

THE HYDROTHERMAL SYSTEM IN CENTRAL TWIN FALLS COUNTY, IDAHO

By R.E. Lewis and H.W. Young

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DONALD PAUL HODEL, SECRETARY
U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
230 Collins Road
Boise, ID 83702

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CONTENTS

	Page
Abstract.....	1
Introduction.....	2
Purpose and scope.....	2
Previous investigations.....	4
Acknowledgments.....	5
Well- and spring-numbering system.....	5
Geology.....	5
Hydrology.....	10
Occurrence and movement of thermal water.....	11
Chemical characteristics of the hydrothermal system.....	17
Chemical geothermometers.....	23
Stable isotopes.....	27
Geophysics.....	32
Electrical resistivity.....	32
Conceptual model of the system.....	34
Summary and conclusions.....	36
References cited.....	41

ILLUSTRATIONS

[Plate in back of report]

Plate 1.	Electrical resistivity profiles, Twin Falls County, Idaho	
Figure 1.	Map showing location of study area	3
2.	Diagram showing well- and spring-numbering system	6
3.	Map showing generalized geology	8
4.	Map showing locations of wells, springs, electrical resistivity sounding stations, and lines of electrical resistivity profiles.	14
5.	Hydrographs showing water-level fluctuations in wells	16
6.	Trilinear diagram showing chemical composition of water from selected wells and springs	20
7-9.	Graphs showing:	
7.	Relation of chloride concentration to water temperature.....	21
8.	Comparison of reservoir temperatures estimated using silica and sodium-potassium-calcium geothermometers.....	27
9.	Relation between deuterium and oxygen-18.....	29

TABLES

	Page
Table 1. Records of wells.....	12
2. Selected chemical constituents, temperatures, and isotopic compositions for thermal and cold water.....	18
3. Estimated reservoir temperatures and free energy of formation for selected water samples.....	25

CONVERSION FACTORS

The following conversion table is included for the convenience of those who prefer to use metric (International System) units rather than the inch-pound units. Chemical data for concentrations are given in mg/L (milligrams per liter) or µg/L (micrograms per liter), which are, within the range of values presented, numerically equal to parts per million or parts per billion, respectively.

Multiply inch-pound unit	By	To obtain metric unit
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
calorie per second (cal/s)	4.184	joule per second; watt
calorie per centimeter second-degree Celsius [cal/(cm·s·°C)]	4.184×10^2	watt per meter degree kelvin
microcalorie per square centimeter-second (µcal/cm ² ·s) heat flow unit (HFU)	4.184×10^{-2}	watt per square meter
cubic foot (ft ³)	0.02832	cubic meter
cubic mile (mi ³)	4.168	cubic kilometer
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
microsiemens per centimeter at 25 degrees Celsius (µS/cm)	1.000	micromhos per centimeter at 25 degrees Celsius
mile (mi)	1.609	kilometer
pound per square inch (psi)	0.069	bar
square mile (mi ²)	2.590	square kilometer

Conversion of °C (degrees Celsius) to °F (degrees Fahrenheit) is based on the equation °F = (1.8)(°C) + 32. Water temperatures are reported to the nearest one-half degree.

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Abstract

Thermal water in Twin Falls County has been used for space heating, large-scale greenhouse operations, and aquaculture since the mid-1970's. More recently, the artesian pressure of the system has been used to generate electricity through the use of low-head hydrogenerators. Increased utilization of the thermal water has caused aquifer pressures to decline in recent years. Near the city of Twin Falls, pressure declines of up to 15 pounds per square inch since 1984 have been documented, and water levels in some formerly flowing thermal wells have declined to below land surface.

The thermal water is principally in the silicic volcanic rocks of the Idavada Volcanics. Electrical resistivity soundings indicate that the Idavada Volcanics are continuous over most of the area; thickness ranges from about 700 to 3,000 feet and averages about 2,000 feet. Reservoir volume is about 240 cubic miles. Temperatures of water sampled range from 26 degrees to nearly 50 degrees Celsius in wells completed in the upper part of the reservoir; the warmest water is near Twin Falls.

Most of the thermal water is a sodium bicarbonate type. The maximum fluoride concentration was 22 milligrams per liter. Elevated concentrations of chloride between about 50 and 150 milligrams per liter observed in water nearly 20 degrees Celsius are the result of mixing with shallower, cooler water that has been influenced by percolation of irrigation water in areas where hydraulic heads in the thermal system are below land surface.

Carbon-14 concentrations in selected thermal water samples indicate ages of 1,000 to 15,000 years. The water becomes progressively older northward along proposed ground-water flowpaths. On the basis of transit times in the system between 10,000 to 15,000 years and the reservoir volume determined from electrical resistivity data, recharge (hence, discharge in a static system) is about 5 to 7 cubic feet per second. Net heat flux in the area, calculated as the sum of the heat removed advectively in underflow leaving the system and the amount of heat lost conductively at the surface, is about 2.2 heat flow units.

INTRODUCTION

Twin Falls County is in south-central Idaho between the Snake River and the Nevada border (fig. 1). Surface geothermal manifestations are limited to three hot springs issuing from faults: Miracle and Banbury Hot Springs in western Twin Falls County near the Snake River, and Nat-Soo-Pah Warm Spring south of Twin Falls. Except for development of the Banbury Hot Springs spa around 1910, little use was made of the thermal resource until the 1970's. During the mid-1970's, residents in western Twin Falls County began using the resource, which is readily available from relatively shallow wells, for aquaculture and space heating. In the late 1970's, motivated perhaps by the energy crisis, more and more residents installed wells to take advantage of the thermal water.

Interest in developing the resource continues, and additional wells are being installed for space heating, greenhouse operations, and aquaculture. Most recently, low-hydraulic head hydrogenerators have been installed on some flowing warm-water wells to produce electricity for sale to power companies. Discharge from these wells is generally sufficient to produce some electricity, but the heat content of the resource is not used. Increased consumption of the thermal water has caused sharp declines in aquifer pressures, particularly in the Twin Falls area, where declines of as much as 15 psi (pounds per square inch) since 1984 have been documented.

Chemical analyses of thermal water (Lewis and Young, 1982) in the nearby Banbury Hot Springs and adjacent areas indicate a hot-water dominated system; measured water temperatures in these areas range from about 30° to 72 °C. On the basis of these chemical similarities and measured water temperatures, thermal water is presumed to be pervasive in aquifers beneath a large part of Twin Falls County.

Purpose and Scope

This report describes the results of a study to define the areal extent and thickness of the hydrothermal reservoir in Twin Falls County and to propose a generalized conceptual model of the system. Specific objectives of the study, done in cooperation with the Idaho Department of Water Resources, were to evaluate the existing resource as to its volume, temperature, pressure, and water chemistry, and to determine the effects of present development on the resource.

The study was limited to Twin Falls County. Some geologic, geochemical, and hydrologic data for the hydrothermal system were available from earlier studies. However, information about the subsurface at depths greater than 1,000 ft was sparse. One well for which data were available was drilled to 2,525 ft; several

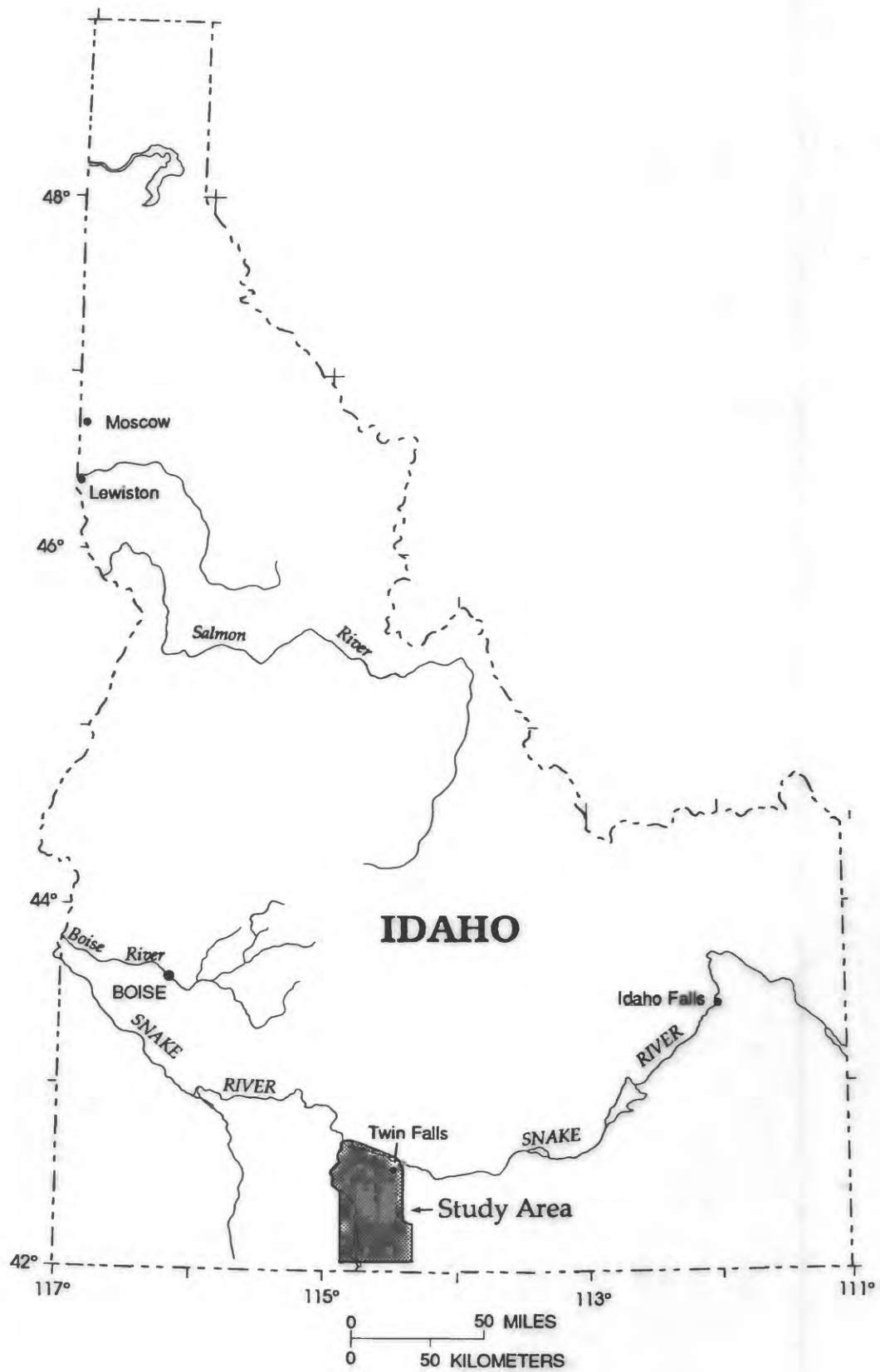


Figure 1.--Location of study area.

others were drilled to depths between 1,200 and 2,200 ft. Direct-current electrical resistivity soundings conducted during the summer of 1985 as part of the study provided valuable information about the subsurface at depths less than about 6,000 ft. Interpretation of computer-generated subsurface profiles constructed from the soundings provided the basis for determining the thickness of the Idavada Volcanics over much of the study area.

Previous Investigations

Few in-depth hydrologic, geophysical, or geochemical studies have been done in the Twin Falls area. Stearns and others (1937) first documented the presence of thermal water in the Twin Falls area. Fowler (1960) estimated seepage losses from Salmon Falls Creek Reservoir and ground-water underflow from that area during a reconnaissance ground-water investigation. Chemical analyses of water from 25 wells were included in Fowler's report, but thermal-water resources were not discussed. Ross (1971) summarized existing data, which included some chemical analyses. In their assessment of the hydrothermal resources of Idaho, Young and Mitchell (1973) included water analyses from several thermal wells and springs in and near the study area. Lewis and Young (1982) investigated the nature and occurrence of thermal water in the Banbury Hot Springs area near the western margin of the study area. They determined that, on the basis of isotopic and chemical data, thermal water was probably more than 1,000 years old and estimated reservoir temperatures were between 70° and 100 °C, although the hottest water temperature measured during their investigation was 72 °C.

Malde and others (1963) included most of the study area in their reconnaissance geologic mapping of the west-central Snake River Plain. Malde and Powers (1972) mapped the geology of the northwestern part of the study area. Rember and Bennett (1979), using existing geologic data, compiled a generalized geologic map that includes the entire Twin Falls study area. Surficial geology in the area was mapped by Scott (1982).

Sass and others (1971) included most of the Snake River Plain in a discussion of heat flow in the Columbia Plateau. Largely on the basis of observed volcanism and hot-spring activity, Blackwell (1969) included the Columbia Plateau in his postulated Cordilleran Thermal Anomaly Zone of high heat flow. Brott and others (1976, 1978) discussed heat flow in the western Snake River Plain in general terms and, for a regional model of the Snake River Plain, estimated that the highest heat flow values were about 3.0 HFU (heat flow units; 1 HFU = 10^{-6} cal/cm²s) at the margins of the plain, near the northern boundary of the study area.

Geophysical work in the area has been limited to broad, regional studies. Magnetic gradients and contours for the study area are included on the aeromagnetic map of Idaho by Zietz and

others (1978). Gravity contours for parts of northern Twin Falls County are included in a report by Mabey and others (1974).

Acknowledgments

The writers appreciate the assistance given by many landowners in Twin Falls County who allowed access to their property for measuring water levels and collecting water samples, and who supplied information about wells and springs in the area. Special thanks go to Leah Street, geologist, Idaho Department of Water Resources, who assisted in some of the data collection and provided valuable editorial and technical assistance.

Well- and Spring-Numbering System

The well- and spring-numbering system (fig. 2) used by the U.S. Geological Survey in Idaho indicates the location of wells or springs within the official rectangular subdivision of the public lands, with reference to the Boise base line and Meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters and a numeral, which indicate the 1/4 section (160-acre tract), 1/4-1/4 section (40-acre tract), 1/4-1/4-1/4 section (10-acre tract), and serial number of the well within the tract. Quarter sections are lettered A, B, C, and D in counterclockwise order from the northeast quarter of each section. Within quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 10S-17E-4CDA1 is in the NE1/4SE1/4SW1/4 sec. 4, T. 10 S., R. 17E., and was the first well inventoried in that tract. Springs are designated by the letter "S" following the last numeral; for example, 13S-18E-29AAD1S.

GEOLOGY

The study area includes most of Twin Falls County on the southern margin of the western Snake River Plain in south-central Idaho. The area is characterized by a broad, undulating plain interrupted in places by prominent volcanic buttes. Several perennial streams cross the study area in deeply incised canyons. The largest streams include Salmon Falls and Rock Creeks, which drain directly to the Snake River. In addition, several large irrigation canal systems cross the area. Water in these canals is diverted from the Snake River and Salmon Falls Creek Reservoir. To the north, the plain terminates abruptly at the canyon of the Snake River. To the south, the plain rises gradually toward the Rock Creek Hills. The canyon of Salmon Falls Creek was considered the western boundary of the study area and the course of Rock Creek was considered the eastern boundary.

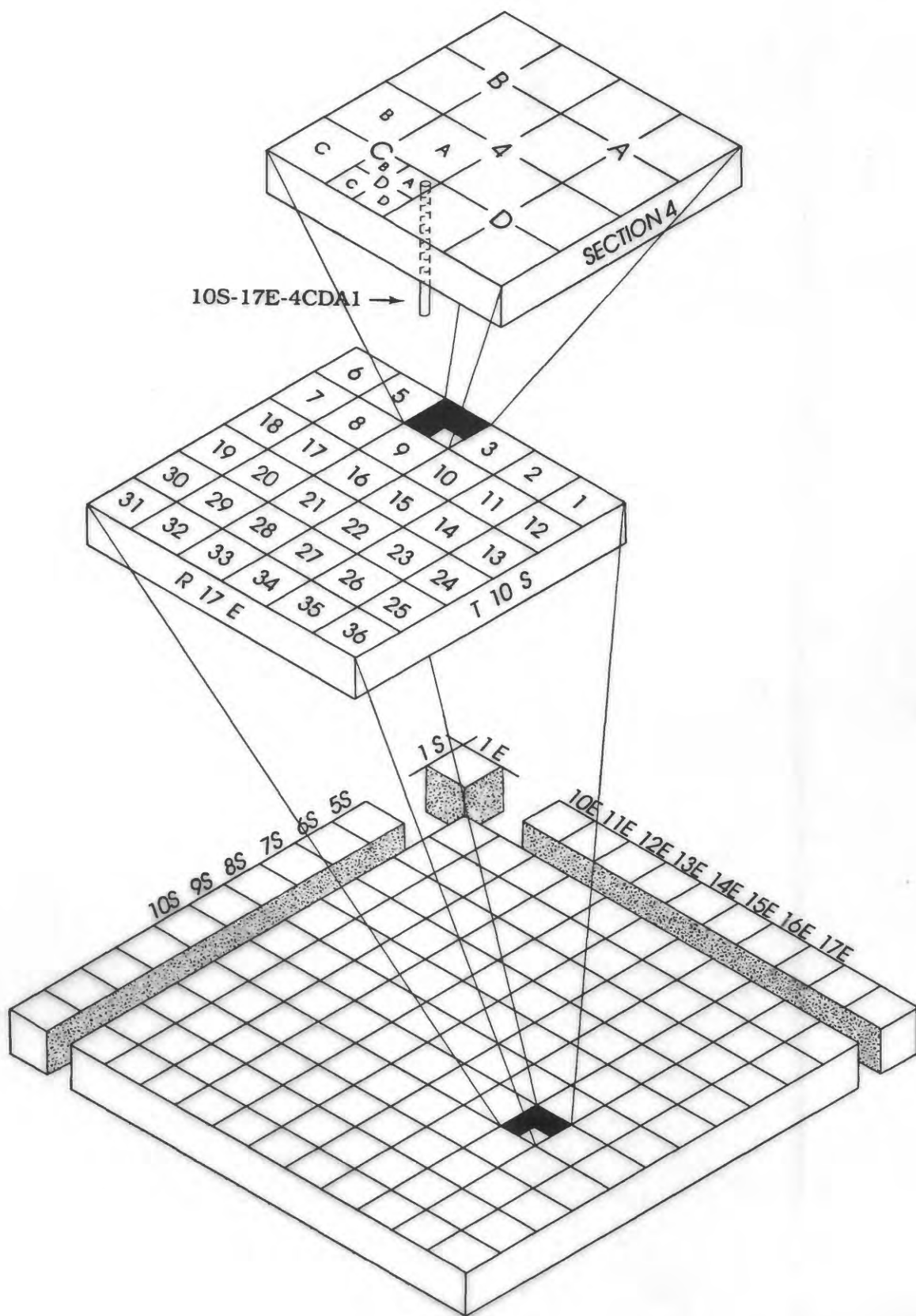


Figure 2.--Well- and spring-numbering system.

Rocks underlying the Twin Falls area and most of southwestern Idaho consist of clastic and volcanic rocks ranging in age from middle Miocene to middle Pliocene. These rocks are exposed in mountainous areas of the Owyhee Mountains to the west, in the Jarbidge Mountains in Nevada, and in the plateau incised by the Bruneau and Jarbidge Rivers (outside the study area). For this report, the rocks were divided into the following units: (1) undifferentiated Paleozoic sedimentary rocks, (2) Tertiary Idavada Volcanics, (3) Tertiary Banbury Basalt, (4) Quaternary-Tertiary basalt, (5) Quaternary basalt, and (6) Quaternary sedimentary rocks. Areal distribution and descriptions of these units are shown in figure 3.

Paleozoic sedimentary rocks, consisting chiefly of upper Paleozoic marine sediments, are exposed only in a small area southeast of Hollister. Although not reported in logs of wells drilled to depths of about 2,500 ft, this unit probably underlies most of the study area. Thickness of the unit is mostly unknown; however, in the Jarbidge Mountains to the southwest, sedimentary rocks underlying the Idavada Volcanics are as much as 4,900 ft thick (Schroeder, 1912, p. 36).

The Idavada Volcanics consist chiefly of silicic welded tuffs and lava flows of Miocene age (L.M. Gard and J.W. Hasler, U.S. Geological Survey, written commun., 1963). Actual chemical composition varies according to the mode of occurrence. The predominant welded ash flows and less abundant lava flows are composed almost entirely of silicic latite and contain phenocrysts of andesine, clinopyroxene, hypersthene, and magnetite. Glass in the groundmass is rhyolitic in composition (Malde and Powers, 1972). The Idavada Volcanics are exposed in deep canyons of several streams along the southern boundary of the Snake River Plain and in the low hills along the southern part of the study area. Drillers' logs indicate that rhyolitic members of this unit are widespread in the subsurface. Total thickness of the unit is unknown; however, northwest of Buhl, the unit exceeds 2,000 ft (Malde and Powers, 1972). In the drainage immediately to the east of Buhl, the Idavada Volcanics are more than 2,950 ft thick and consist mainly of vitric tuffs (L.M. Gard and J.W. Hasler, U.S. Geological Survey, written commun., 1963). In the Bruneau River canyon, jointing in the dense, silicic latite flows of the Idavada Volcanics is apparent in polygonal columns 330 to 430 ft high (L.M. Gard and J.W. Hasler, U.S. Geological Survey, written commun., 1963). If such jointing is pervasive throughout most of the formation, and if the joints are open at depth, vast avenues could be afforded for the migration and circulation of thermal water.

Banbury Basalt overlies the Idavada Volcanics and consists chiefly of olivine basalt flows of late Miocene age. Drillers' logs indicate that this unit underlies much of the study area. Thickness of Banbury Basalt is variable; however, northwest of the

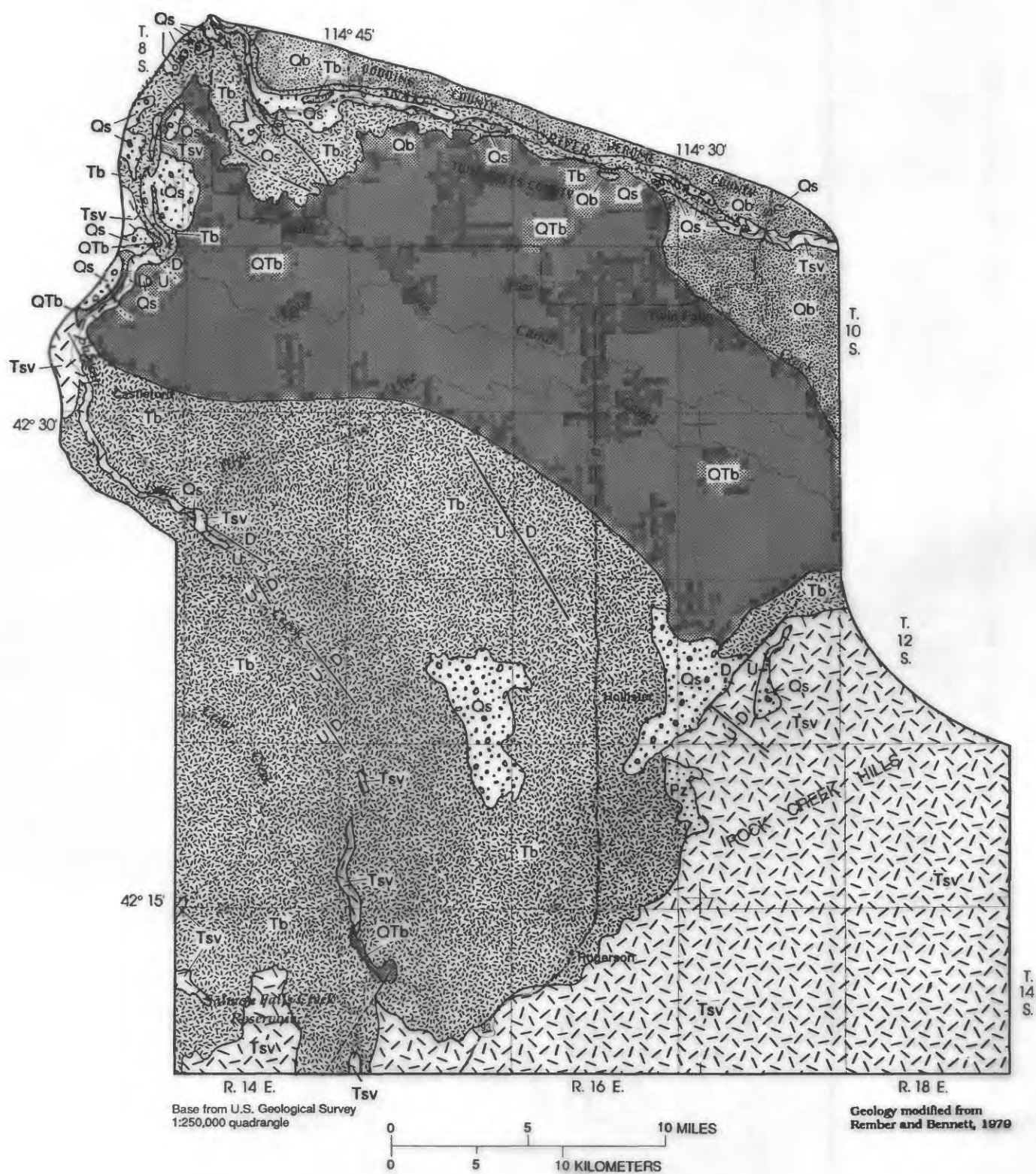
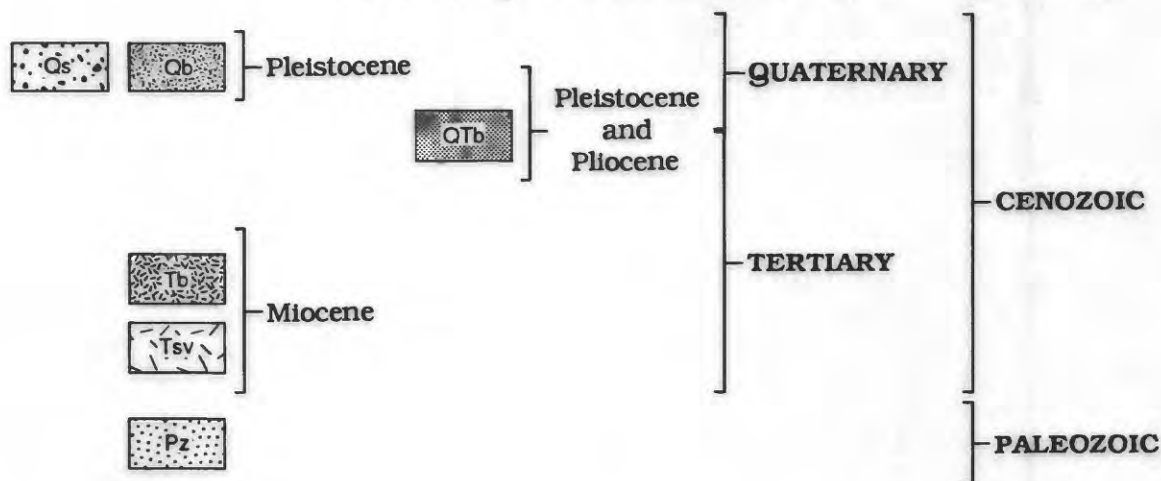


Figure 3.—Generalized geology.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

- QUATERNARY SEDIMENTARY ROCKS**--Chiefly terrace deposits of boulders, cobbles, and pebbles of basalt of the Melon Gravel. Includes the Tuana Gravel and surficial deposits of clay, silt, sand, and gravel
- QUATERNARY BASALT**--Chiefly lava flows of olivine basalt of Hansen Butte. Includes some lava flows of olivine basalt of the Snake River Group
- QUATERNARY-TERTIARY BASALT**--Chiefly lava flows of olivine basalt of the Glens Ferry Formation. Includes some detrital basin-fill deposits consisting of clay, silt, sand, and gravel
- TERTIARY BASALT**--Chiefly lava flows of olivine Banbury Basalt. Locally interbedded with minor amounts of stream and lake deposits
- TERTIARY SILICIC VOLCANICS**--Chiefly thick layers of devitrified welded tuff and some bedded vitric tuff and lava flows of the Idavada Volcanics
- PALEOZOIC SEDIMENTARY ROCKS**--Chiefly marine sediments
- FAULT**--Dashed where approximately located; dotted where concealed.
 U, upthrown side; D, downthrown side
- GEOLOGIC CONTACT**

Figure 3.--Generalized geology--Continued.

study area, thickness of the unit is more than 980 ft (Malde and others, 1963). Malde and Powers (1972) divided the Banbury Basalt into three parts: (1) A lower part about 400 ft thick, composed of flows of decomposed amygdaloidal olivine basalt, each usually about 15 ft thick; (2) a middle part about 100 ft thick, composed mainly of brownish sand and pebble gravel in lenticular stream deposits that include some light-colored clay, silt, and diatomite in lake deposits, and beds of silicic volcanic ash; and (3) an upper part as much as 500 ft thick in places, composed mainly of olivine basalt and some porphyritic plagioclase-olivine basalt in columnar flows as much as 50 ft thick.

Quaternary-Tertiary basalt, consisting chiefly of olivine basalt flows of the Glenns Ferry Formation, upper Pliocene and lower Pleistocene age, is exposed in the northern part of the study area. The basalt flows generally form sheetlike layers within the detrital deposits of the Glenns Ferry Formation. Thickness of the Glenns Ferry Formation west of the study area exceeds 2,000 ft (Malde and others, 1963); however, in the study area, maximum thickness probably does not exceed 500 ft.

Quaternary basalt, consisting chiefly of olivine basalt flows of Pleistocene and Holocene age, is exposed in the northern part of the study area. This unit is composed generally of basaltic lava flows that originated from several prominent buttes in or near the study area. Thickness of the unit is variable, but thickness of individual flows probably does not exceed 50 ft.

Quaternary sedimentary rocks consist chiefly of surficial deposits of fluviatile sand and gravel. Near the Snake River, these deposits include the Melon and Tuana Gravels of late and early Pleistocene age, respectively. Loess (wind-deposited silt) of varying thickness mantles the entire area.

Several northwest- or northeast-trending normal faults have been mapped in the study area (fig. 3). The northwest-trending faults generally are downthrown on the northeast. Most displacement along these faults occurred during late Miocene time; progressively smaller displacements occurred during Pliocene and Pleistocene time. Idavada Volcanics and Banbury Basalts show the greatest displacement, whereas rock units above the Banbury Basalts show little or no displacement. Variability in thickness to the top of the Idavada Volcanics reported in drillers' logs may be due to displacement along unmapped faults in the area or to the nature of emplacement of the basalt.

HYDROLOGY

For ease of discussion, ground water in the study area is divided into two components: (1) A shallow aquifer system in which temperatures are near ambient, ground-water flowpaths are

relatively short and direct from areas of recharge to areas of discharge, and (2) a deep aquifer system in which water temperatures are much higher than ambient surface temperatures and ground-water flowpaths are long and presumably circuitous. It is from this deep system that thermal water is produced. For a better understanding of local hydrology, a brief description of the shallow aquifer system follows. Further quantification or description of the shallow system is not attempted. The deep system is described fully in a later section.

The shallow system includes one or more aquifers in Banbury Basalt or thin sedimentary interbeds, and locally perched ground water. Ground-water movement is generally northward or north-westward toward the Snake River. Ground water in this system may be confined to some degree, but hydraulic heads are well below land surface. Wells completed in the shallow aquifers produce water with temperatures generally less than about 20 °C; however, some produce water with higher temperatures as a result of mixing with thermal water that has migrated upward from the deep system along faults.

Recharge is primarily from precipitation and runoff in the low hills to the south and southeast where mean annual precipitation is as much as 45 in. Seepage from irrigation canals and ditches that liberally transect the county also contributes a considerable amount of recharge. Some recharge is upward leakage from the deep hydrothermal system. Although the amount cannot be quantified, general areas of upward leakage can be identified by the elevated temperatures of water at shallow depths and, to some degree, by the water chemistry. Some recharge also may be from infiltration of direct precipitation, but this amount is small and probably does not exceed 10 percent of the total precipitation in this area of the Snake River Plain (Kjelstrom, 1986, sheet 2).

Near Filer, percolation of excess water applied for irrigation has formed a perched water zone just below land surface. Hundreds of cubic feet per second of water from this zone are discharged annually to the Snake River in drain ditches installed to intersect the top surface of the perched water.

Occurrence and Movement of Thermal Water

Thermal water from 20° to 44 °C is primarily under artesian conditions in the Idavada Volcanics of Miocene age. Drillers' logs indicate some thermal water in the overlying Banbury Basalt, but that water probably has moved upward along fractures from artesian aquifers in the Idavada Volcanics.

Wells that produce thermal water are in the northern part of the study area in or near Twin Falls and Buhl (fig. 4 and table 1). Depths of wells range from 350 to 2,220 ft. Until recently, most of these wells were artesian and flowed at land

Table 1.--Records of wells

[C = chemical analysis; DL = driller's log; F = flowing,
no head measured; P = well pumped recently; R = reported;
--, no data reported]

Well or spring number	Altitude of land surface (feet)	Reported depth of well (feet)	Potentiometric surface		Water temperature (°C)	Remarks
			Altitude above or below (-) land surface (feet)	Date measured		
9S-14E- 9ADA1	2,930	750	362	3-14-79	33.0	DL, C
			143	4-17-85		
9ADC1	3,000	850	167	3-15-79	31.5	DL
			112	5- 1-85		
10ADA1	3,000	950	93	3-16-81	37.0	DL, C
			92	4-17-85		
10DDb1	3,260	2,030	-F	2-11-81	28.5	DL, C
13DBB1	3,375	165	20	3-16-81	18.5	DL
			6	4-18-85		
13DDD1	3,514	900	-36	3-17-81	26.0	DL, C
			-18	4-17-85		
14BDB1	3,127	906	297	3-16-81	32.5	C
			244	5- 1-85		
23ABD1	3,345	350	29	3-27-79	25.0	DL, C
			-2R	4-17-85		
24BBC1	3,430	140	-59	3-16-81	19.5	DL
9S-15E-12CCA1	3,050	1,423	31	7-21-81	44.0	DL, C
			83	3-19-82		
			174	5- 1-85		
13BBD1	3,442	610	-426	2- 4-82	23.0	C
29CDD1	3,710	--	-57	3-17-81	13.5	
31CBB1	3,790	645	-153	3-16-81	23.0	DL
			-189	4-17-85		
31CCB1	3,812	1,058	-159	3-16-81	31.0	DL, C
9S-16E-20ADD1	3,487	1,247	196	4-15-85	30.5	DL, C
9S-17E-28BDA1	3,612	2,050	118	5-19-80	27.0	DL, C
			73	4-18-85		
29ACD1	3,150	730	495R	5-17-70	42.0	DL, C
32DDA1	3,637	1,280	95R	3-17-81	39.5	DL, C
			42	4-18-85		
33BBB1	3,170	750	566R	3-17-82	39.0	
10S-13E-10BBC1	3,823	1,435	-384	7-17-85	--	DL
20ADA1	3,418	1,280	169R	4-24-81	41.5	DL, C
			131	4-17-85		
10S-14E- 1CCA1	3,840	688	-70	3-17-81	--	DL
10S-16E- 3DDD1	3,705	105	-67	3-17-81	15.0	DL
8CDA1	3,782	942	-27	3-18-81	31.5	DL, C
9CCD1	3,775	136	-53	3-17-81	13.5	
11DDA1	3,695	80	-37	3-17-81	14.5	DL
12DDA1	3,695	--	-25	3-17-81	13.0	
17BCB1	3,822	950	-58	3-17-81	21.0	
21AAB1	3,849	--	-78	3-17-81	15.0	
33ADD1	4,040	180	-109	3-17-81	13.0	

Table 1.--Records of wells--Continued

Potentiometric surface						
Well or spring number	Altitude of land surface (feet)	Reported depth of well (feet)	Altitude above or below (-) land surface (feet)	Date measured	Water temperature (°C)	Remarks
10S-17E- 4CAC1	3,662	1,480	72R	4- 4-81	38.0	DL, C
4CDA1	3,661	2,220	73R	3-17-81	37.0	DL, C
			32	4-17-85	--	
5DAA	3,650	1,450			30.5	DL, C
10BDB1	3,710	1,700			35.5R	DL, C
14CCD1	3,788	1,154	-48	3-17-81	30.5	DL, C
			-49	4-17-85		
10S-17E-19CCC1	3,797	--	-13	3-17-81	13.5	
26ABA1	3,820	700	-26	8-19-80	10.5	DL
26DCC1	3,845	80	-24	3-17-81	15.0	
33BBA1	3,927	776	-140	10- 9-80	17.0	
34CDD1	3,910	--	-75	10- 9-80	15.0	
11S-14E- 5DAD1	3,931	546	-64	9-24-80	14.0	
11S-15E- 2BBB1	4,142	1,010	-232	3-17-81	--	
11S-16E- 2DDD1	4,115	500	-271	3-18-81	--	
6DBA1	4,149	975	-263	3-17-81	20.0	
9CCC1	4,219	500	-271	3-18-81	14.0	DL
12BCC1	4,154	400	-299	3-19-81	15.0	
14DAD1	4,247	400	-300	3-18-81	11.0	
20CCC1	4,390	600	-414	8-19-80	--	
21DCC1	4,296	866	-529R	1-19-62	25.5R	
22ACD1	4,290	--	-275	3-18-81	--	
23ABA1	4,260	515	-282	3-18-81	--	
24AAA1	4,290	657	-467R	6- 5-57	20.5	DL
25BAB1	4,333	927	-676	3-19-81	11.0	
27CCC1	4,302	580	-275	3-19-81	--	DL
34CCB1	4,310	643	-490	8- 6-56	21.0	
36CCB1	4,331	--	-436	3-19-81	17.0	
11S-17E-16DDA1	4,218	700	-580R	12-14-54	19.0	C
29BBB1	4,415	800	-625	3-16-81	30.0	DL, C
12S-15E-10CBB1	4,482	1,017	-548	4- 6-82	18.5	DL, C
12S-17E-31BAB1	4,542	200	-F	4-23-81	37.0	C
13S-15E- 1DAD1	4,569	2,255	-214	6- 1-81	43.5R	
			-213	4-16-85	--	
2DDD1	4,565	600	-207P	4-19-81	19.0	DL, C
13S-16E- 1DCC1	4,615	600	-8	3-19-81	36.0R	
12DAA1	4,742	700	-125	3-19-81	36.5R	DL
18DAA1	4,640	1,565	-100	3-10-82	31.0R	DL
14S-15E-14CBD1	4,930	2,525	31	7-16-85	32.0	DL, C
14S-15E-16DDC1	4,938	1,890	25	3-18-81	26.0	DL, C
35CDD1	5,190	900	-165	8- 8-85	32.0	C

EXPLANATION

- ° 13DDD WELL AND REFERENCE NUMBER (table 2)
- 33 SPRING AND REFERENCE NUMBER (table 2)
- 5 ■ ELECTRICAL RESISTIVITY SOUNDING STATION AND NUMBER
- A — A' LINE OF ELECTRICAL RESISTIVITY PROFILE (plate 1)

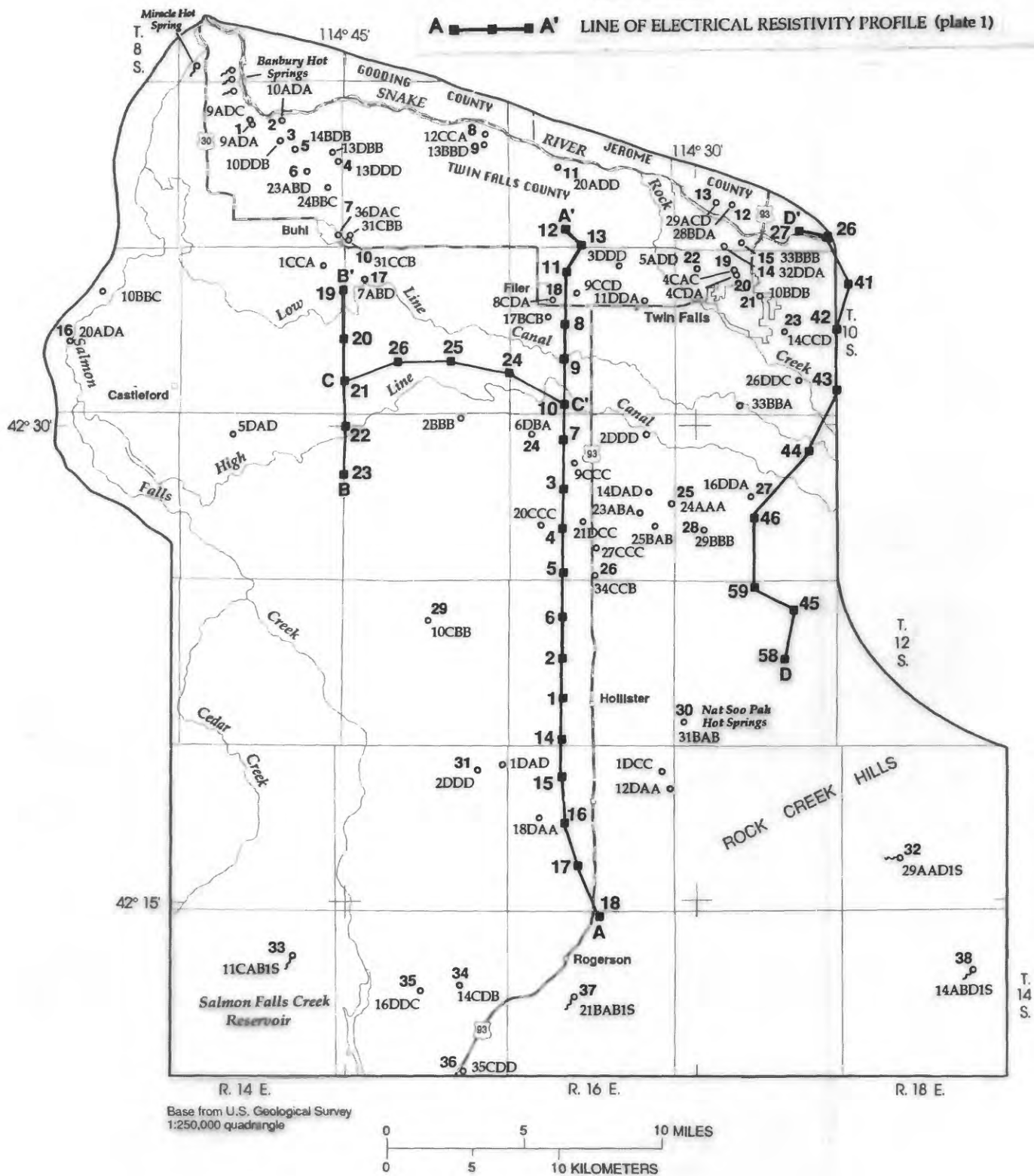


Figure 4.--Locations of wells, springs, electrical resistivity sounding stations, and lines of electrical resistivity profiles.

surface. Increased use of the resource has caused a general decline in aquifer pressures. The largest decline, near Twin Falls, was as much as 35 ft (15 psi) between September 1984 and January 1986 (fig. 5). Several artesian wells in the area have ceased to flow, and owners now must pump to utilize thermal water.

Ground-water temperatures range from 30.5° to 42.0 °C and increase northwestward. Near Buhl, ground-water temperatures range from 29.0° to 37.0 °C and also increase northwestward; however, water chemistry indicates some mixing with shallow cold ground water, so temperatures may not be representative of water in the deeper system.

Wells west of Castleford and west and northwest of Rogerson and near Hollister also produce thermal water. Depths of wells west of Castleford and Rogerson range from 1,280 to 2,525 ft. These wells are completed in the Idavada Volcanics and produce water with temperatures that range from 26.0° to 41.5 °C. East of Hollister, 37 °C water is produced from several wells less than 200 ft deep drilled near a former hot spring issuing from a northeast-trending fault.

Two wells 1,565 ft and 1,960 ft deep southwest of Hollister produce thermal water. Artesian head in these wells is below land surface. Both wells are completed in the Idavada Volcanics, and reported water temperatures are 31.0° and 43.5 °C.

Configuration of the potentiometric surface of thermal water in the Idavada Volcanics is largely unknown, and hydraulic head distribution in the Idavada Volcanics cannot be determined with confidence. Many of the reported water levels are not representative of aquifer pressures in the thermal system because the wells commonly are not cased to sufficient depths to be sealed off adequately from shallow aquifers in the overlying Banbury Basalt and younger sediments. Consequently, water-level or pressure-head measurements made in these wells represent a composite potentiometric surface. Contour-surface maps constructed on the basis of such measurements would be irregular and possibly misleading.

As a result of their investigations in the Banbury Hot Springs area, Lewis and Young (1982, p. 10) suggested a general northwestward movement of thermal water in the Idavada Volcanics in the area east of Salmon Falls Creek. In that area, head differentials were about 300 ft along proposed flowpaths 4.5 and 6.5 mi long. These differentials indicated hydraulic gradients between 0.009 and 0.013. Additional measurements made during the present study in several deep wells near Hollister indicate hydraulic gradients of 0.009 and 0.011. Data are insufficient to project these gradients northward much beyond Hollister or northeast across the mapped fault; however, hydraulic heads of about 4,500 ft indicate potential for at least some northward ground-water movement.

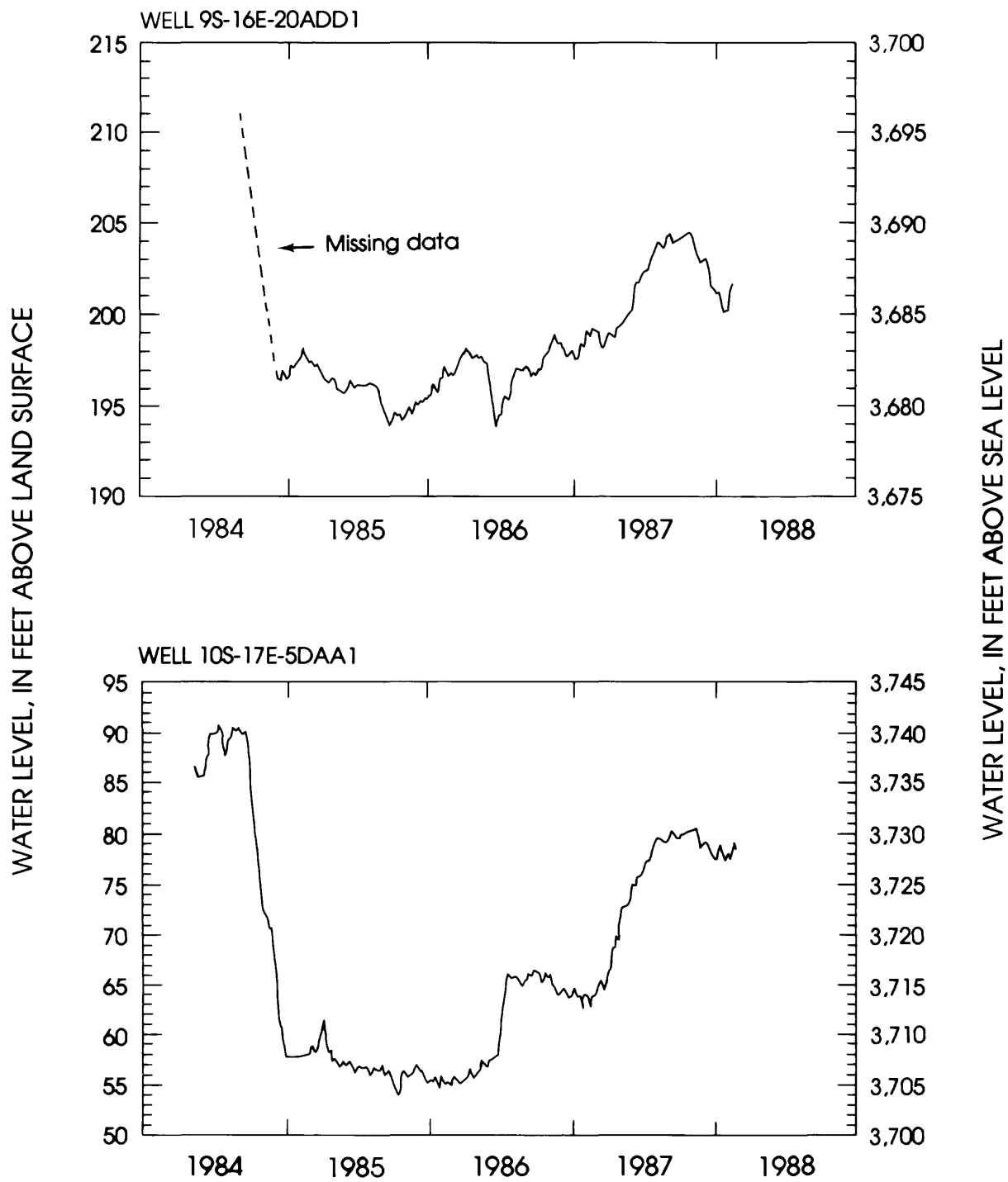


Figure 5.--Water-level fluctuations in wells.

CHEMICAL CHARACTERISTICS OF THE HYDROTHERMAL SYSTEM

Chemical analyses of sampled ground water in the study area permit assessment of probable origins of the water. Most thermal water in the study area exhibits similarities that imply a similar origin or flowpath through the system. Some of the sampled water shows the effects of mixing with irrigation water or cooler water from other aquifers. Other thermal water is chemically unique and may represent water from an adjacent hydrothermal system whose chemistry is influenced by a different host rock.

Water samples from 31 wells and 3 springs in the Twin Falls area were obtained for chemical analyses (table 2). Chemical analyses of thermal water from one well and one spring sampled by Lewis and Young (1982) and Young and Lewis (1982), respectively, also are included in table 2. Locations of sampling sites are shown in figure 4.

Chemical compositions of sampled water are plotted in a trilinear diagram (fig. 6). As shown on the composite plotting field, definite water types are apparent.

Cold springs with temperatures less than 20 °C (samples 32, 33, 37, and 38) are in the mountains to the south of the study area in what is probably the recharge area. Plots of water samples from these springs cluster on the diagram apart from those of higher temperature water samples from the study area. Water from cold springs is a calcium bicarbonate type and has a near-neutral pH; concentrations of dissolved solids are generally less than 200 mg/L.

The highest temperature thermal water (samples 8, 13, 14, 15, 19, 20, and 21) is a sodium bicarbonate type; concentrations of dissolved solids are 250 to 350 mg/L. This water is slightly alkaline (pH values range from 8.6 to 9.3) and contains high concentrations of fluoride (9.7 to 22 mg/L).

Plots of low-temperature thermal water samples (1, 2, 3, 4, 5, 6, 9, and 18) cluster along a line between the cold and highest temperature water groups (fig. 6) and probably represent water that has undergone normal cation exchange reactions between calcium and sodium and dissolution of minerals along flowpaths in the aquifer (Hem, 1985, p. 96). This water, like that in the highest temperature group, is a sodium bicarbonate type and is slightly alkaline (pH values range from 7.8 to 8.1) but contains lower concentrations of dissolved solids and fluoride.

Plots of water samples 23-28 and 31 cluster in an area removed from all other sampled water. Water temperatures in this group of samples are about 20 °C, and concentrations of dissolved

Table 2.--Selected chemical constituents, temperatures, and isotopic compositions for thermal and cold water

[Data for reference number 1 from report by Lewis and Young, 1982; data for reference number 33 from report by Young and Lewis, 1982; chemical concentrations are in milligrams per liter unless otherwise noted; $\mu\text{S}/\text{cm}$, microsiemens per centimeter; $^{\circ}\text{C}$, degrees Celsius; total alkalinity distributed as HCO_3 and CO_3 = at the water temperature; $\mu\text{g}/\text{L}$, micrograms per liter; <, less than]

Reference number (fig. 4)	Well or spring number	Reported well depth below land surface (feet)	Date of collection	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Water temperature ($^{\circ}\text{C}$)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
1	9S-14E-9ADA1	750	3-14-79	326	8.4	33.0	53	11	0.5	61	3.9	150	4
2	10ADA1	950	2-9-81	328	8.1	37.0	60	13	1.2	58	4.1	140	0
3	10DB1	2,030	2-11-81	352	7.8	28.5	64	16	2.3	55	5.8	150	0
4	13DD1	900	3-27-79	321	8.3	26.0	82	7.4	.2	62	5.6	140	0
5	14DB1	906	2-11-81	358	7.8	32.5	71	18	2.2	54	6.0	150	0
6	23ABD1	350	3-27-79	330	8.1	25.0	87	17	1.1	53	7.5	160	0
7	36DAC1	904	3-14-79	499	7.9	29.0	66	36	5.4	61	10	170	0
8	9S-15E-12CCA1	1,423	6-23-81	427	9.3	44.0	75	1.5	.1	96	1.5	78	38
9	13BBD1	610	7-21-81	382	9.1	23.0	52	8.9	2.4	73	1.9	95	19
10	31CCB1	1,058	6-24-81	522	7.9	31.0	72	39	5.6	65	11	160	0
11	9S-16E-20ADD1	1,247	9-6-84	367	9.1	30.5	67	2.0	.05	82	2.9	110	19
12	9S-17E-28BDA1	2,050	3-18-81	482	9.0	27.0	82	1.9	.1	110	3.5	140	25
13	29ACD1	730	12-7-77	445	8.8	42.0	74	2.5	.1	110	1.9	140	22
14	32DDA1	1,280	4-8-81	412	9.2	39.5	66	1.9	.1	99	1.9	110	23
15	33BBB1	750	7-24-85	415	9.3	39.0	67	1.6	.06	96	2.8	120	28
16	10S-13E-20ADA1	1,280	4-24-81	902	8.6	41.5	41	12	.2	170	.9	77	2
17	10S-15E-7ABD1	1,991	2-10-81	525	8.0	25.0	71	35	4.5	63	12	160	0
18	10S-16E-8CDA1	942	6-23-81	291	8.0	31.5	59	20	3.9	37	7	130	0
19	10S-17E-4CAC1	1,480	4-22-81	358	8.8	38.0	59	3.3	.2	78	2.5	100	10
20	4CDA1	1,185	2-20-79	358	8.6	37.0	56	4.8	.5	75	2.7	120	5
21		2,220	2-9-81	360	8.5	37.0	59	4.3	.2	78	2.3	120	5
22	5DAA1	1,450	7-24-85	364	8.6	30.5	55	8.6	.4	74	6.3	110	4
23	14CCD1	1,154	4-8-81	407	7.8	30.5	50	37	6.8	31	4.9	100	0
24	11S-16E-6DBA1	975	6-24-81	1,260	7.9	20.0	55	78	66	94	11	230	0
25	11S-16E-24AAA1	657	3-19-81	1,340	7.8	20.5	39	56	88	110	6.8	360	0
26	34CCB1	643	4-22-81	851	7.7	21.0	58	94	26	22	6.8	150	0
27	11S-17E-16DDA1	700	4-23-81	581	7.9	19.0	56	37	24	38	3.6	120	0
28	29BBB1	800	4-22-81	635	7.9	30.0	59	44	17	49	12	160	0
29	12S-15E-10CBH1	1,017	3-18-81	241	7.8	18.5	48	23	8.4	13	2.9	120	0
30	12S-17E-31BAA1	200	4-23-81	464	7.7	37.0	19	31	13	43	11	270	0
31	13S-15E-20DD1	600	3-19-81	660	7.7	19.0	57	62	22	38	6.1	150	0
32	13S-18E-29ADA1S	--	5-13-81	75	6.7	9.0	56	5.4	1.3	6.0	5.0	34	0
33	14S-14E-11CAB1S	--	6-27-78	91	7.0	12.0	35	7.2	1.2	5.9	2.6	30	0
34	14S-15E-14CDB1	2,525	8-4-82	225	7.8	32.0	58	21	2.0	18	6.9	120	0
35	16DDC1	1,890	3-18-81	217	7.5	26.0	60	22	2.6	19	5.8	110	0
36	35CDD1	900	7-25-85	204	7.6	32.0	65	18	2.3	18	4.7	100	0
37	14S-16E-21BAA1S	--	2-10-81	278	7.6	7.5	52	34	5.4	19	3.6	120	0
38	14S-18E-14ABD1S	--	5-13-81	40	6.0	4.5	38	2.6	.7	3.4	2.6	20	0

Table 2.--Selected chemical constituents, temperatures, and isotopic compositions
for thermal and cold water--Continued

Reference number (fig. 4)	Well or spring number	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Dissolved solids (calculated)	Nitrite plus nitrate as N (NO ₂ +NO ₃)	Arsenic As (µg/L)	Boron B (µg/L)	Lithium Li (µg/L)	δD o/oo	δ ¹⁸ O o/oo
1	9S-14E-9ADA1	24	11	3.6	246	<0.01	16	110	60	-132	-16.9
2	10ADA1	25	12	3.6	246	.31	13	90	60	-132	-17.2
3	10DDB1	27	13	2.5	259	.39	16	90	60	--	--
4	13DD1	21	9.9	4.8	262	.34	8	140	80	--	--
5	14BDB1	27	13	2.5	268	.50	17	90	60	-131	-17.1
6	23ABD1	22	14	2.4	283	.61	8	20	50	--	--
7	36DAC1	61	31	1.9	356	1.5	9	120	70	-130	-16.8
8	9S-15E-12CCA1	24	14	16	304	.13	56	200	30	-134	-17.2
9	13BBD1	28	20	11	263	<.01	40	300	20	--	--
10	31CCB1	75	38	1.7	388	1.6	8	100	70	--	--
11	9S-16E-20ADD1	20	11	12	272	.32	20	110	21	-131	-16.9
12	9S-17E-28BDA1	18	10	22	341	<.01	46	330	20	-137	-17.7
13	29ACD1	15	16	16	326	.23	24	220	4	-135	-16.9
14	32DDA1	25	15	14	301	.59	32	160	6	-132	-17.0
15	33BBB1	20	15	11	299	.36	--	110	--	-138	-17.0
16	10S-13E-20ADA1	230	71	2.2	567	.09	28	100	190	-133	-16.8
17	10S-15E-7ABD1	69	35	1.6	371	1.5	9	80	70	-129	-16.4
18	10S-16E-8CDA1	17	11	3.7	223	.66	8	80	30	-127	-16.7
19	10S-17E-4CAC1	21	14	9.7	247	.35	18	160	10	-131	-17.4
20	4CDA1	20	12	12	248	.42	17	180	<4	--	--
21		22	14	11	255	.47	16	180	10	-131	-17.4
22	5DA1	26	21	11	262	.54	--	100	--	-132	-17.1
23	14CCD1	51	31	1.0	263	.89	4	0	30	-127	-16.4
24	11S-16E-6DBA1	290	150	.4	863	5.4	6	170	40	-131	-16.4
25	11S-16E-24AA1	260	120	.4	863	6.0	5	270	20	-120	-15.0
26	34CCB1	100	110	4	496	5.0	3	50	20	-139	-17.4
27	11S-17E-16DDA1	90	55	.8	367	3.7	4	60	20	-140	-17.4
28	29BBB1	79	56	1.3	400	4.6	4	110	40	-132	-16.4
29	12S-15E-10CB1	11	9.0	.2	175	.77	4	20	6	-123	-15.4
30	12S-17E-31BAB1	21	6.3	1.9	279	.02	0	120	50	-133	-17.0
31	13S-15E-2DD1	130	65	.6	458	3.2	4	50	20	--	--
32	13S-18E-29AB1S	2.0	1.6	.2	95	.78	0	20	<4	-127	-16.4
33	14S-14E-11CAB1S	5.0	3.1	.2	76	.89	1	20	4	-126	-17.1
34	14S-15E-14CDB1	10	6.8	.7	200	.45	2	50	34	-130	-16.9
35	16DDC1	12	6.4	6	183	.57	3	10	20	-131	-16.7
36	35CDD1	8.8	6.5	.8	174	.52	--	20	--	-132	-16.8
37	14S-16E-21BAB1S	17	16	.3	208	1.8	6	60	<4	-120	-14.6
38	14S-18E-14AB1S	3.4	1.3	.1	62	.17	0	5	4	-123	-16.2

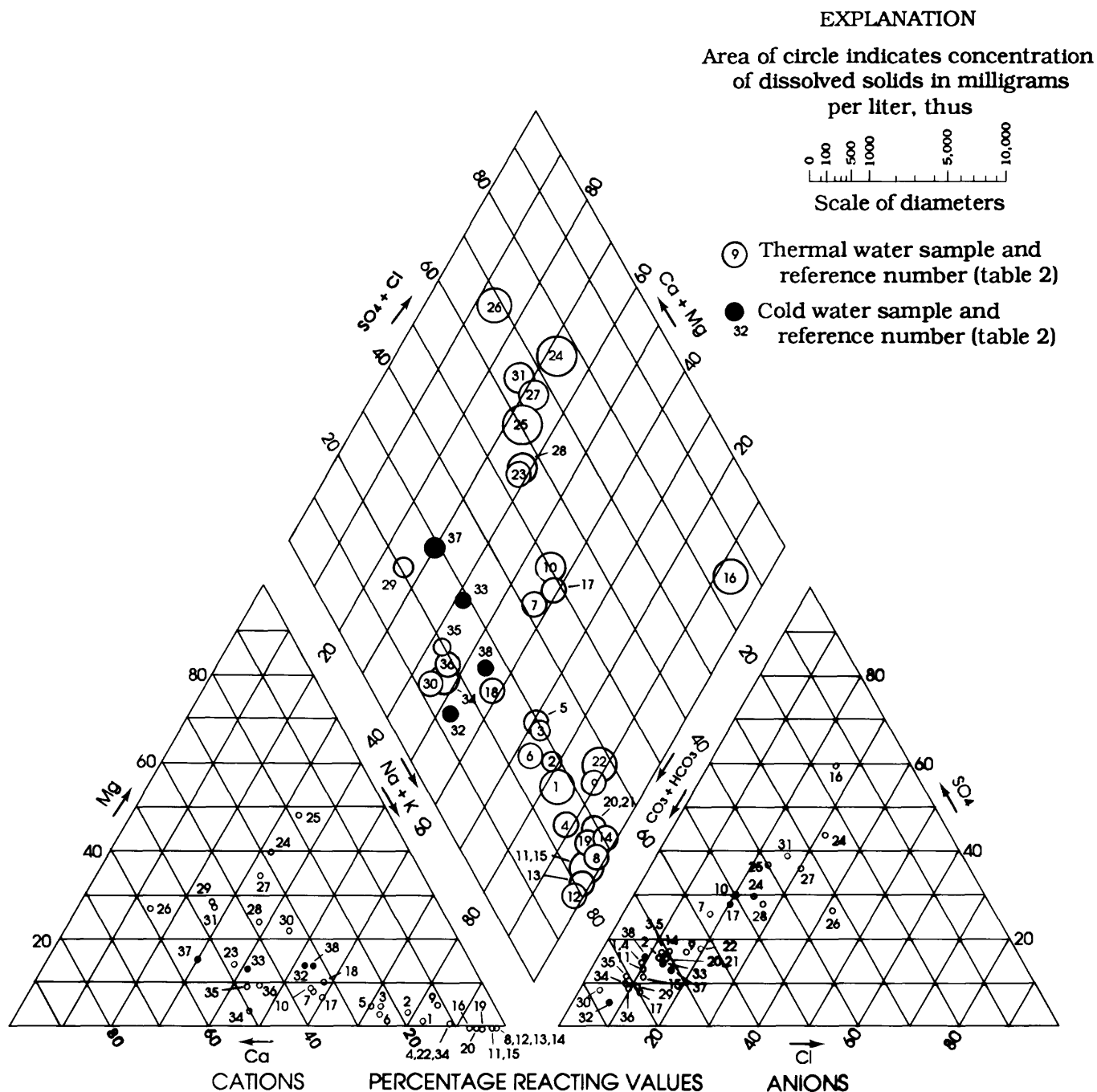


Figure 6.--Chemical composition of water from selected wells and springs.

solids are the highest of any in the study area. Concentrations of dissolved chloride and nitrite plus nitrate as nitrogen (hereafter referred to as nitrogen) are particularly high. These water samples are from wells in and near areas of extensive irrigation southwest of Twin Falls. Hydraulic heads in these wells are below land surface. The high concentrations of dissolved solids probably result from percolation of applied irrigation water containing an excess of dissolved constituents leached from overlying soils. Although the temperatures of about 20 °C may indicate some thermal water influence, the anomalous chemical composition of samples 23-28 and 31 precludes quantification of that influence. Plots of samples 7, 10, and 17 are removed from the main group of irrigation-affected water but the water still exhibits characteristically elevated concentrations of dissolved solids, chloride, and nitrogen. This water also has been affected by percolation of irrigation water, but to a lesser degree.

The relation between water temperature and chloride concentration is shown in figure 7. Chloride, a conservative constituent, does not enter readily into ion-exchange reactions and can be useful in determining the degree of mixing between different types of water. Greater concentrations of chloride in warm water are the result of longer flowpaths and greater residence time in the system than cold water; hence, more time is available for water-rock reactions and dissolution of chloride from the aquifer material. In general, cold water from the recharge areas is low in chloride; warm water contains a proportionally greater concentration of chloride. The warmest water in the Twin Falls system contains the greatest concentration of chloride and generally is observed in the northern part of the area.

Water that is influenced by mixing with shallow ground water affected by irrigation is highest in dissolved chloride relative to other ground water and is skewed radically from the rest of the population. Concentrations of nitrogen in the mixed water samples are generally greater than 0.5 mg/L and typically range from nearly 1 to 6.0 mg/L. For thermal water that apparently is unaffected by irrigation (concentration of nitrogen less than about 0.5 mg/L), a positive correlation between water temperature and concentration of chloride is indicated.

Chemical and isotopic patterns of the thermal water indicate that faults acting as barriers to ground-water movement have compartmentalized the aquifer into smaller, separate subsystems (Lewis and Young, 1982, p. 6). Some water may be entering the Twin Falls system across the eastern boundary of the study area and may account for some chemical disparity, but additional chemical and isotopic analyses of water east of the study area are needed to verify or disprove this possibility.

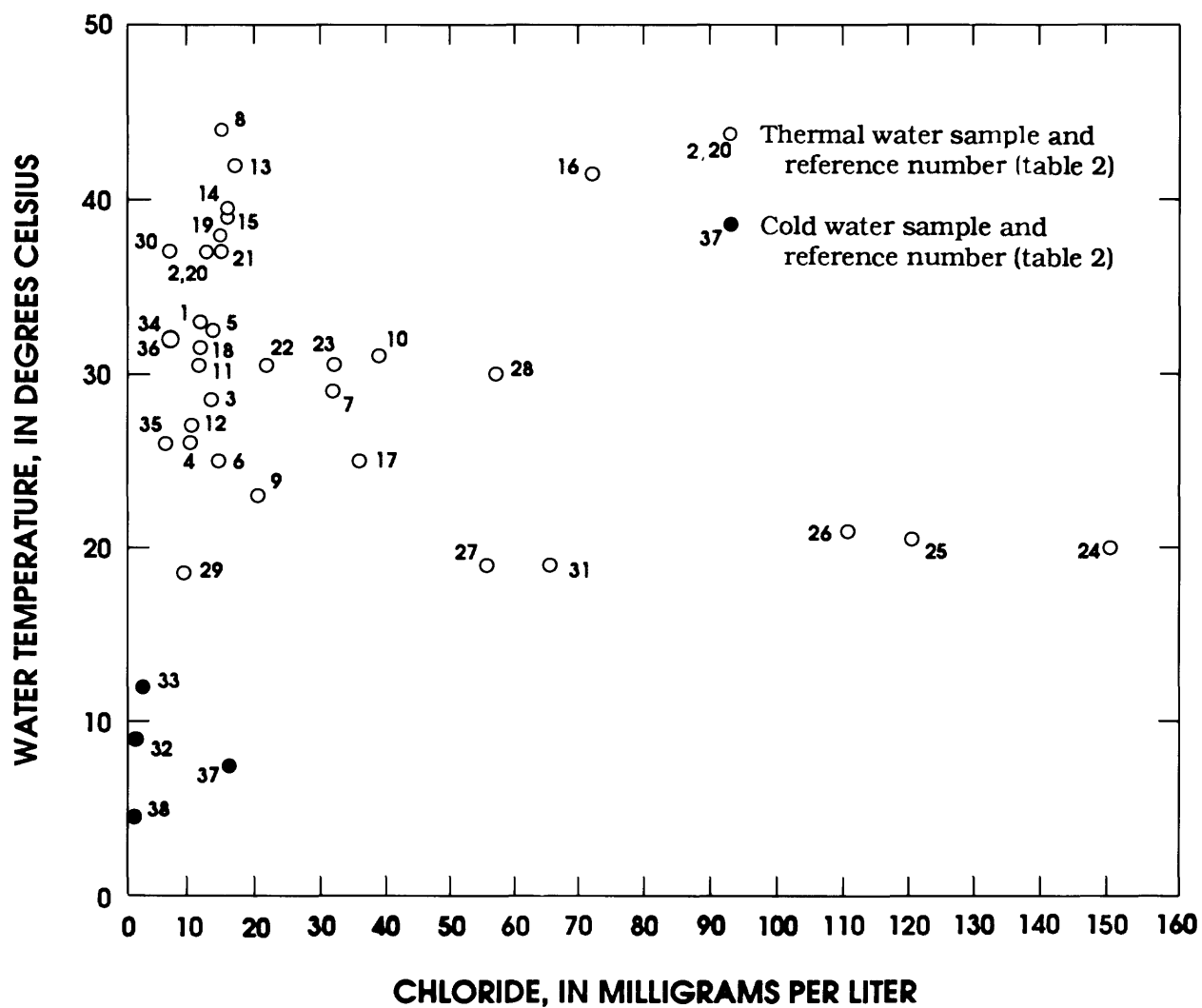


Figure 7.--Relation of chloride concentration to water temperature.
(Reference numbers correspond with table 2.)

Thermal water represented by sample 16 in figures 6 and 7 is a sodium sulfate type, a strikingly different chemical composition than other sampled thermal water in the study area. Although the chloride concentration in sample 16 is high, similar to water influenced by irrigation, the dissolved nitrogen concentration is low. Sample 16 probably does not represent a mixture of any two types of water in the study area but may represent water from a separate, chemically unique hydrothermal system adjacent to the Twin Falls system. Additional studies may be necessary to determine the existence of adjacent hydrothermal systems and to understand their relation to the Twin Falls system. Probable origins and mixing patterns of the thermal water are discussed further in the section, "Isotopes."

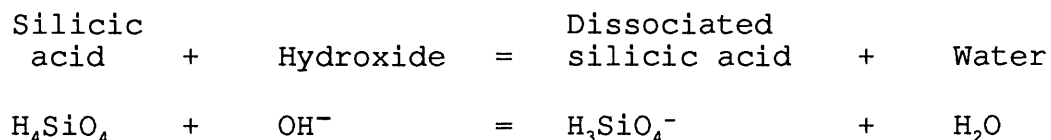
Chemical Geothermometers

Temperature and pressure control the equilibrium concentration of all reactive solutes in thermal fluids (Ellis and Mahon, 1977, p. 144). Numerous techniques have been used to correlate thermal reservoir temperature with geochemical or isotopic data; however, few of these chemical geothermometers have been calibrated. The silica geothermometer (Fournier and Rowe, 1966) equates reservoir temperatures with the solubility of quartz. The Na-K-Ca (sodium-potassium-calcium) geothermometer (Fournier and Truesdell, 1973) empirically equates reservoir temperature with ratios of temperature-dependent concentrations of the ions. Both techniques have been used successfully in many investigations of medium- to high-temperature hydrothermal systems, but their application in low-temperature hydrothermal systems has not been as confidently demonstrated. Some caution must be exercised in applying these techniques to thermal water in the Twin Falls area.

Reservoir temperatures in the Twin Falls area were estimated using the silica and Na-K-Ca or cation geothermometers. Temperatures estimated by these chemical geothermometers are valid only for hot-water systems and only if the following basic assumptions are met (Fournier and others, 1974, p. 259): (1) Chemical reactions at depth are temperature dependent, (2) an adequate supply of chemical constituents used for the thermometry is present in the aquifer, (3) chemical equilibrium is established at depth between the hot water and the specific aquifer mineral, (4) reequilibration of the chemical composition of the hot water as it rises to the surface is negligible, and (5) hot water rises rapidly to the surface with no dilution or mixing with cooler, shallow ground water.

Dissolved silica (SiO_2) reported in chemical analyses actually is present as silicic acid (H_4SiO_4) and various dissociated species (particularly H_3SiO_4^-); SiO_2 does not exist as a distinct dissolved species in nature (Brook and others, 1979, p. 22). In alkaline

water, hydroxide (OH^-) reacts with the silicic acid to reduce the proportion of silicic acid to total dissolved silica in the temperature-dependent reaction:



For thermal water with a pH greater than 8.3, reported values for dissolved silica ($\text{H}_2\text{SiO}_4 + \text{H}_3\text{SiO}_4^-$) were corrected for dissociation of silicic acid at the well temperature and pH, and reservoir temperatures were estimated assuming equilibrium with quartz or chalcedony (table 3). The actual pH of water in the thermal aquifer will be slightly lower than the pH measured at the well; calculation of true aquifer pH might increase the H_3SiO_4^- -corrected quartz temperature by 5° or 10 °C (R.H. Mariner, U.S. Geological Survey, written commun., 1980). However, calculation of aquifer pH requires consideration of acid-base equilibria, distribution of acidic gases between steam (if any) and water, and the effect of temperature on the equilibria (Ellis and Mahon, 1977, p. 250).

When using the Na-K-Ca geothermometer, Fournier and Potter (1979, p. 1543) observed that for many low-temperature, magnesium-rich waters, estimated reservoir temperatures were too hot. On the basis of cation ratios involving magnesium, they devised equations and graphs to attenuate the adverse effect of magnesium on the Na-K-Ca geothermometer by applying an empirical correction for the concentration of magnesium. This magnesium correction was applied to the Na-K-Ca geothermometer when estimated reservoir temperatures were greater than 70 °C and concentrations of magnesium were greater than 1.0 mg/L.

Reservoir temperatures for 19 wells were calculated using a Fortran version of SOLMNEQ, a mineral-solution program (Kharaka and Barnes, 1973). Temperatures were not calculated for water where concentrations of nitrogen greater than about 0.5 mg/L indicated some mixing with shallow ground water influenced by irrigation. Where reservoir temperatures were estimated, water temperatures at the surface ranged from 23.0° to 44.0 °C. Estimated reservoir temperatures and calculated departure from theoretical equilibrium (degree of saturation or unsaturation) for aragonite, calcite, chalcedony, and quartz are given in table 3. Relative departure values were considered in determining which of the geothermometers might provide the best estimate of reservoir temperature. However, the thermal water is near saturation with respect to calcite at the measured well temperature and might

Table 3.--Estimated reservoir temperatures and free energy of formation for selected water samples

Reference number (fig. 4)	Spring or well number	Estimated reservoir temperatures (°C) based on geothermometers						¹ Free energy of formation at reported water temperatures			
		Well-head temperature (°C)	Silica, quartz- conductive	Silica, quartz- conductive H ₂ SiO ₄ - corrected	Sodium-potassium- calcium ²	Silica, chalcedony	Silica, chalcedony H ₂ SiO ₄ -corrected	Aragonite	Calcite	Chalcedony	Quartz
1	³ 9S-14E- 9ADA1	33.0	104	101	75	75	71	0.2	0.3	0.5	1.1
2	10ADA1	37.0	111	--	73	81	--	-.1	.1	.9	1.2
3	10DDb1	28.5	114	--	79	85	--	-.5	-.3	1.1	1.4
4	³ 13DDD1	26.0	126	--	97	97	--	-.3	-.3	.9	1.5
5	14BDB1	32.5	119	--	77	90	--	-.4	-.1	1.1	1.4
8	9S-15E-12CCA1	44.0	122	96	93	93	66	0	.2	.6	.9
9	13BBD1	23.0	104	94	60	74	63	.5	.8	.9	1.2
11	9S-16E-20ADD1	30.5	16	104	108	87	74	-.2	.1	.9	1.2
12	9S-17E-28BDA1	27.0	126	117	121	99	88	-.2	0	1.1	1.4
13	29ACD1	42.0	121	111	91	93	82	-.1	.2	.8	1.2
14	32DDA1	39.5	115	96	96	86	66	-.6	-.4	.7	1.0
15	33BBB1	39.0	116	94	115	87	63	-.3	0	.6	1.0
16	10S-13E-20ADA1	41.5	93	87	41	62	56	0	.2	.5	.8
18	10S-16E- 8CDA1	31.5	110	--	76	80	--	-.1	.1	1.0	1.3
19	10S-17E- 4CAC1	38.0	110	102	90	80	72	-.2	-.1	.8	1.1
20	4CDA1	37.0	107	102	84	78	72	-.1	.1	.8	1.1
21	4CDA1	37.0	110	106	81	80	76	-.3	-.1	.8	1.2
30	12S-17E-31BAB1	37.0	62	--	53	29	--	2	.3	-.2	.5
32	13S-18E-29AAD1S	9.0	107	--	74	78	--	-3.6	-3.3	1.4	1.5
34	14S-15E-14CDB1	32.0	109	--	67	80	--	-.4	-.1	1.0	1.3
35	16DDC1	26.0	111	--	61	81	--	-.9	-.7	1.1	1.4
36	35CDD1	32.0	115	--	59	86	--	-.9	-.6	1.0	1.3
37	14S-16E-21BAB1S	7.5	104	--	40	74	--	-.8	-.6	1.4	1.5
38	14S-18E-14ABD1S	4.5	89	--	63	59	--	-5.1	-4.9	1.2	1.4

¹Values are departure from theoretical equilibrium in kilocalories; positive values indicate supersaturation, (--) values indicate unsaturation. Calculations from computer program SOLMNEQ (Kharaka and Barnes, 1973).

²Corrected for concentration of magnesium where applicable (Fournier and Potter, 1979).

³From Lewis and Young (1982).

further reduce the credibility of reservoir temperatures estimated using the Na-K-Ca geothermometer.

R.H. Mariner (U.S. Geological Survey, written commun., 1979) suggested that chalcedony may control the silica solubility in thermal water with surface temperatures below about 75 °C. This suggestion appears to hold true for most of the low-temperature thermal water in the area.

Fournier and others (1979, p. 20) showed that, on a plot of reservoir temperatures estimated by the silica geothermometer versus reservoir temperatures estimated by the Na-K-Ca geothermometer, most data points representing samples of unmixed water in equilibrium with or reequilibrated with the aquifer minerals after mixing lie on or near an equal-temperature line. Data points that lie significantly above the equal-temperature line represent water that probably contains anomalous concentrations of silica as a result of evaporation or dissolution of amorphous silica from the aquifer material.

Data points that plot significantly below the equal-temperature line represent water that probably has mixed with another type of water and has not reequilibrated with the surrounding rock. Alternatively, the water may have precipitated silica during cooling (Na-K-Ca proportions remain unchanged) or may have precipitated calcite or aragonite as a result of loss of carbon dioxide without adjustment of sodium and potassium through reaction with clays, zeolites, or other minerals (Fournier and others, 1979, p. 21).

A comparison of reservoir temperatures estimated using the silica and Na-K-Ca geothermometers is shown in figure 8. Data points for only a few samples plot on or near the equal-temperature line. As suggested by Fournier and others (1979, p. 20), this water probably is not mixed, although it could be mixed water that has reequilibrated with the surrounding rock. Data points for samples 11, 12, 14, 15, 19, and 20 plot significantly below the equal-temperature line and probably represent mixed water that has not reequilibrated. For this water, the silica geothermometer probably gives the better estimate of reservoir temperature.

Data points for samples 5, 16, 34, 35, and 36 plot significantly above the equal-temperature line and represent water that probably contains amorphous silica dissolved from aquifer materials. For this water, the Na-K-Ca geothermometer probably gives the better estimate of reservoir temperature.

On the basis of the most reliable H_3SiO_4^- -corrected silica and Na-K-Ca geothermometers, maximum reservoir temperatures in the study area may range from about 70° to 80 °C. However, because temperature data from deep drill holes in this area are

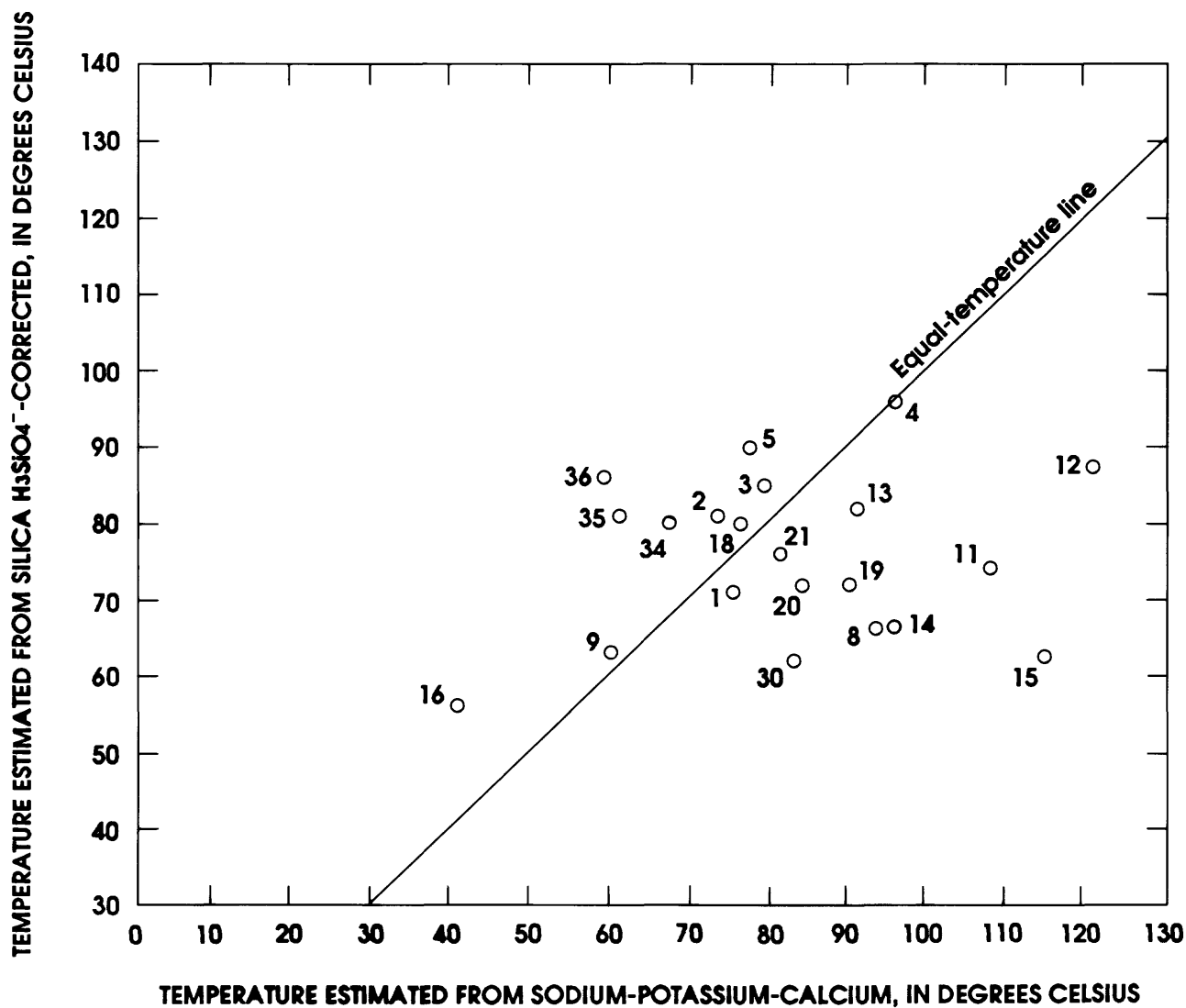


Figure 8.--Comparison of reservoir temperatures estimated using silica and sodium-potassium-calcium geothermometers.
(Reference numbers correspond with table 3.)

unavailable, and because the accuracy of geothermometry has not been demonstrated fully in low-temperature systems, some caution should be exercised when using these reservoir temperatures estimated with chemical geothermometers.

Stable Isotopes

Isotopic compositions of thermal fluids can be used to indicate relative age, origin, and mixing patterns in a geothermal system. Samples of thermal and cold water were collected from selected wells and springs for analysis of the stable isotopes ^{16}O (oxygen-16), ^{18}O (oxygen-18), and D (deuterium). Results of these analyses are presented in table 2 and figure 9. Isotopic analyses of water from several thermal wells and cold springs sampled during previous studies (Lewis and Young, 1982; Young and Lewis, 1982) also are included.

Concentrations of these stable isotopes in water from different sources characterize the origin and mixing patterns of the water. Atmospheric water vapor derived from the ocean is depleted in ^{18}O and D. Principal stable molecular species in water are H_2^{16}O , H_2^{18}O , H_2^{17}O , and HDO. In seawater, the proportions of these species are $10^6:2,000:420:316$ (Craig, 1963); this composition is referred to as SMOW (standard mean ocean water). Isotopic composition of precipitation depends on the fraction of water remaining in and temperature of the air mass from which the rain or snow is derived (Ellis and Mahon, 1977, p. 75). Stable isotopes generally are expressed in delta units (δ) and are reported in permil (‰). These units represent relative deviations in the heavy isotope fraction of water and are defined by Craig (1963) as:

$$\delta = \frac{R_x - R_{std}}{R_{std}} \times 1,000 \quad (1)$$

where R_x is ratio or isotopic composition of the sample, and R_{std} is the corresponding ratio for SMOW.

A worldwide study of freshwater samples by Craig (1963) showed that the isotopic relations in cold meteoric water could be expressed by the equation $\delta\text{D} = 8\delta^{18}\text{O} + 10$. This line, commonly referred to as the meteoric water or SMOW line, is shown in figure 9. Precipitation, hence, the slope of the line, may vary regionally. Data points for samples of cold water obtained over the entire Snake River Plain plot along a line represented by the equation $\delta\text{D} = 6.4 \delta^{18}\text{O} - 21$ (W.H. Low, U.S. Geological Survey, oral commun., 1986). Depletion of stable isotopes in meteoric water generally can be correlated with distance from the ocean, latitude, and altitude or temperature. Data points for samples of water affected by nonequilibrium evaporation, as in inland basins,

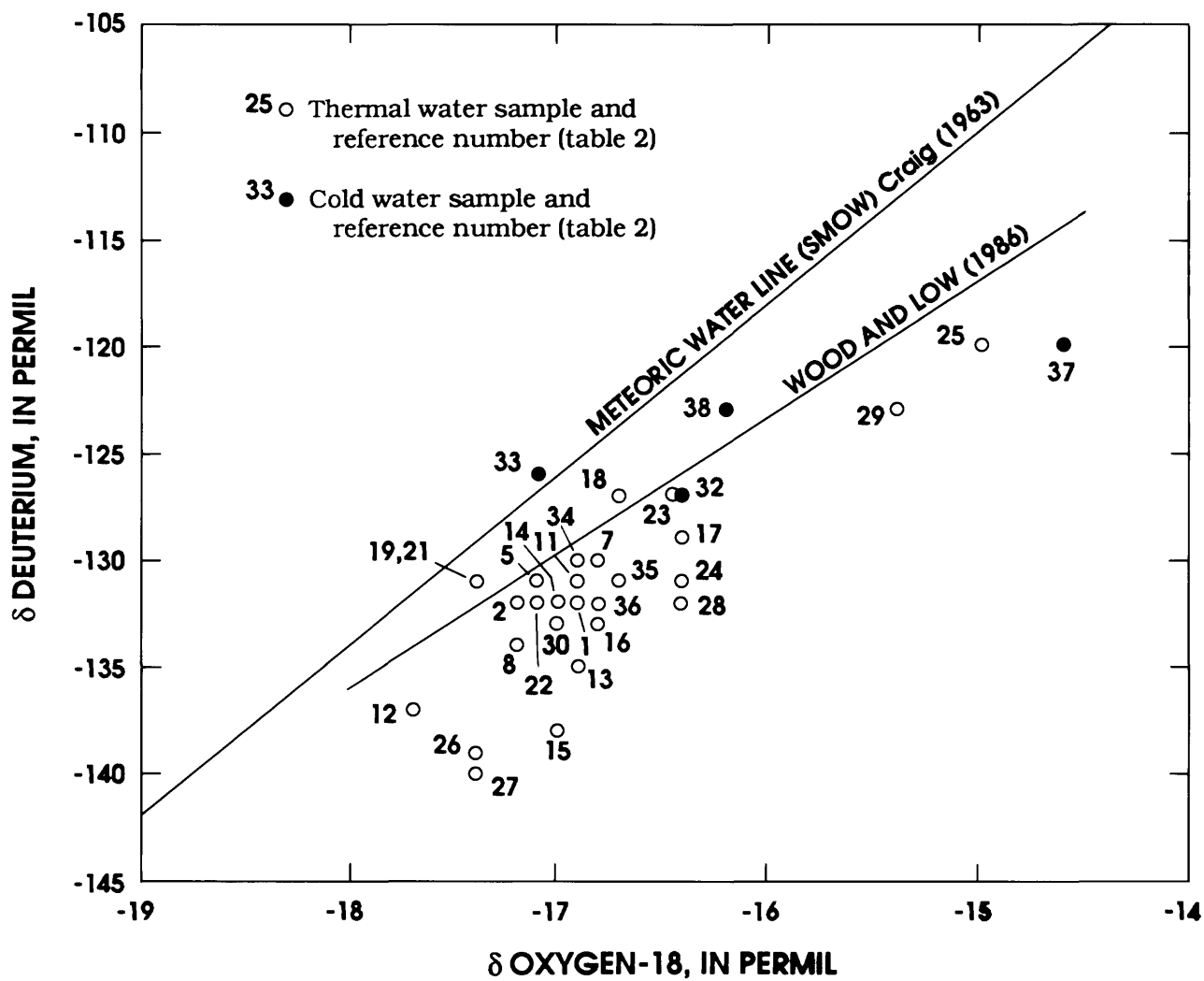


Figure 9.--Relation between deuterium and oxygen-18.

lie off the meteoric line. However, at ordinary air temperatures, isotopic composition of evaporated water is connected approximately to the original isotopic composition of the precipitation $\delta^{18}\text{O}_0\text{D}_0$ by a line expressed by the equation $\delta\text{D} = 5(\delta^{18}\text{O} - \delta^{18}\text{O}_0) + \delta\text{D}_0$ (Ellis and Mahon, 1977, p. 75).

During passage through the aquifer, water retains the D composition characteristic of precipitation in the recharge area. The ^{18}O content in thermal water, however, usually is enriched (becomes less negative) to varying degrees during circulation within the system, as a result of reaction with the more ^{18}O -enriched aquifer material. However, isotope-exchange reactions between water and rock are slow at temperatures below 150°C (Hobba and others, 1979, p. 25) and generally are detected in systems with reservoir temperatures greater than about 100°C (Ellis and Mahon, 1977, p. 92).

Relations between D and ^{18}O for thermal and cold water samples plotted against several meteoric water lines are shown in figure 9. Most of the thermal water samples are clustered between about -130 and -133 ‰ δD and indicate a common general recharge area. Although some enrichment of ^{18}O may be attributed to isotopic exchange between the water and silicates in the rock at the observed temperatures, the oxygen shift apparent in figure 9 is more likely the result of evaporation of the parent water prior to its being recharged. Cold water samples are less depleted in D (less negative); values range from about -120 to -126 ‰. A sample with a temperature of 4°C from a spring in the upper Salmon Falls Creek drainage (Lewis and Young, 1982, p. 20) exhibited δD and $\delta^{18}\text{O}$ values of -127 and -16.7 ‰. This sample probably represents local, present-day meteoric water. Data points for most of the cold samples depicted in figure 9 plot off the meteoric water line. These samples correlate more closely to the local meteoric water line reported by Wood and Low (1986) for the Snake River Plain.

Samples 17, 23, 24, 25, 28, and 29 (fig. 9) are enriched in isotopic composition relative to the main group of thermal water samples. This enrichment may be due to evaporation or may indicate mixing of the thermal water with local irrigation water. The latter possibility is enforced by similar conclusions offered in an earlier section of the report on water chemistry. Most of the thermal water samples that display isotopic enrichment relative to the other samples also contain elevated concentrations of nitrogen and chloride, commonly observed in higher-than-background concentrations in ground water impacted by irrigation practices.

Varying isotopic compositions in the remaining outlying water samples that, from their chemistry, indicate mixing with local irrigation water, may be explained by examining origins of the water used for irrigation. Water most depleted in D probably is

being influenced by irrigation water derived from ground water that originated as recharge outside the study area. Water most enriched in isotopic composition probably is being influenced by irrigation water derived from surface-water sources. These surface-water sources, besides originating somewhere outside the area, are subject to extensive evaporation and enrichment of stable isotopes during delivery through a series of reservoirs and canals. Most of the thermal water samples have consistently more negative deuterium values than the cold samples. Welch and others (1981, p. 85) listed the possible causes of thermal water being more depleted than present-day recharge water:

- (1) The thermal water is partly metamorphic or primary magmatic water.
- (2) The thermal water is a product of condensation subsequent to boiling at depth.
- (3) The source of recharge for the thermal water is at a higher altitude and is therefore cooler than the source of recharge for the cold water.
- (4) The thermal water originated from precipitation during a cooler climatic period.

Neither of the first two explanations lends itself to the conceptual model proposed for the hydrothermal system. Deuterium depletion of about -7 ‰ in the thermal water samples, compared with depletion in present-day cold water samples indicates that recharge might have originated as precipitation at some higher altitude (explanation 3) or during a past, cooler climatic period (explanation 4). Hobba and others (1979, p. 25) indicated a D depletion rate of about -4 ‰ per degree Celsius, which is within the range of -3.2 to -5.6 ‰ per degree Celsius suggested by Dansgaard (1964). On the basis of these estimates and the normal temperature lapse rate of about 2 °C per 1,000 ft, the presence of meteoric water with a D value comparable to that of the thermal water would require climatic conditions about 1° to 2 °C cooler than at present, or would require precipitation at altitudes about 1,000 ft higher than the cold water springs cited in this study.

Young and Lewis (1982, p. 20) analyzed stable-isotope composition in a 4 °C water sample collected from a spring at an altitude of about 8,300 ft in the Salmon Falls Creek drainage. Enrichment of stable isotopes in the cold spring sample relative to enrichment in the thermal water, and the absence of nearby higher topography that would result in precipitation lighter in isotopic composition indicated that none of the water discharging from the hydrothermal system is derived from present-day, local precipitation.

The fourth explanation for the low D content in the thermal water is the most probable. The water originated as precipitation that fell some time in the past when ambient air temperatures were 1° to 2 °C cooler than at present. Cooler climatic conditions must have persisted for a long period of time, rather than for a few tens of years, to have produced sufficient recharge as precipitation depleted in D and probably are correlative with one of the major ice advances in North America.

Denton and Karlen (1973) identified worldwide Holocene glaciation 2,400 to 3,000 years B.P. (before present), during which time average air temperatures were about 3.5 °C cooler than at present, and a post-Wisconsin glacial advance about 4,900 to 5,800 years B.P. In the Grass Valley area of northwestern Nevada, climatic conditions greatly different from those at the present time have not existed since late Wisconsin time--at least 8,000 years (Welch and others, 1981, p. 92). Stable isotope data from the Greenland ice cap (Epstein and Gow, 1970) show significant shifts in δD and $\delta^{18}O$ between 10,000 and 15,000 years B.P., but that isotopic composition has remained nearly constant during the last 8,000 years. Stable isotope data indicate that thermal water in the Twin Falls system is at least 8,000 years old and is possibly 10,000 to 15,000 years old.

GEOPHYSICS

Electrical Resistivity

In June 1985, 26 electrical resistivity soundings were made to aid in the interpretation of subsurface geology and to determine the thickness and extent of the Idavada Volcanics. Locations of electrical resistivity sounding stations and four profile lines are shown in figure 4. Two profiles extend north-south; one parallels U.S. Highway 93 from the Snake River to a point south of Rogerson, the other lies about 8 mi to the west of the first line and runs from near Buhl to a point about 7 mi south. The third profile extends east-west from Highway 93 to a point about 9 mi west, toward Salmon Falls Creek. Data from resistivity soundings made in 1982 by Bisdorf (1987) as part of the Snake River Plain RASA (Regional Aquifer-System Analysis) were used to construct another north-south profile about 10 mi east of Highway 93.

Electrical resistivity soundings were made using the Schlumberger electrode array described by Keller and Frischknecht (1966, p. 92). Sounding data were smoothed manually to eliminate distortions from metal fences, grounded powerlines, and buried telephone cables, and were processed automatically and interpreted as a series of horizontal layers by using a computer program written by Zohdy (1973). Geoelectric cross sections constructed from the Schlumberger sounding data were generalized and are shown

on plate 1. Plots of the electrical sounding curves and a complete description of the data interpretation are included in a report by Bisdorf (1987).

Subsurface geology as represented in the electrical resistivity profiles is discussed as three separate units--a top, a middle, and a bottom (pl. 1). Insofar as possible, these units are correlated with geology as described in previous investigations and geophysical and drillers' logs from wells.

Drillers' logs indicate that rocks in the top unit are predominantly basalt with some interbedded sediments. Malde and others (1963) described these rocks as principally Miocene Banbury Basalt of the Idaho Group, which consists of flows of olivine basalt interbedded locally with minor amounts of stream and lake deposits. Most wells along the lines of the profiles are less than 800 ft deep and produce water generally cooler than 25 °C. Many of the wells are open to more than one aquifer and produce mixed water; therefore, temperature of the water is not necessarily indicative of the warmest temperatures in the top unit. In the electrical resistivity profile (pl. 1), the top unit is represented by apparent resistivities generally greater than 100 but seldom exceeding 450 ohm-m (ohm-meters). In profile A-A', the top unit appears to be about 1,000 to 1,500 ft thick between Rogerson and Hollister. North and northwest of Hollister, the unit is between 800 and 1,200 ft thick, and apparent resistivities are generally greater than about 300 ohm-m. The unit thins northward from Hollister toward the Snake River and westward. Eastward along line D-D', the unit varies in thickness from about 1,500 ft near the base of Rock Creek Hills to about 650 ft near the Snake River.

In the middle unit, apparent resistivities are generally less than 100 ohm-m and locally as low as 10 ohm-m near the center of the unit. Thickness of the unit near Rogerson cannot be determined from profile A-A'; however, thickness ranges from about 3,000 ft near Hollister to about 700 ft northward near the Snake River. Near Hollister, resistivity profiles indicate possible faulting with the downthrown side toward the south. Although not conclusive from the electrical resistivity data, faulting apparent in profile A-A' is coincident with faults previously mapped (Malde and others, 1963; H.R. Covington, U.S. Geological Survey, unpubl. data, on file in Boise, Idaho, office). In profile C-C', the middle unit is generally thinner than in profile A-A' and appears to pinch out between electrical sounding stations 26 and 21. However, additional low-resistivity rock below station 21 indicates the middle unit is displaced downward and actually may continue westward beyond station 21. Profile B-B' indicates a fairly extensive middle layer but does not show extension of the layer as far south as station 23. Along profile D-D', configuration of the middle unit is unclear. Low apparent resistivity values beneath station 58 near the Rock Creek Hills may be the

result of thermal water moving upward along faults near the base of the hills. Several thermal springs in the area were described by Stearns and others (1937). After some apparent displacement, the middle unit thickens toward the Snake River below depths of about 1,000 ft. Previous electrical resistivity work on the Snake River Plain showed no distinct extension of the middle unit northward beyond the Snake River; however, some geologic evidence disputes this (L.V. Street, Idaho Department of Water Resources, oral commun., 1987).

Few wells in the area are drilled to depths sufficient for accurate determination of thickness of the middle unit. Drillers' logs for 1,500- to 2,500-ft deep wells describe silicic volcanic rocks at depths near those indicated by the lower (generally less than 100 ohm-m) electrical resistivity values shown on plate 1. These rocks probably are Idavada Volcanics of Tertiary age, which were mapped by Malde and others (1963) and described as silicic latite, chiefly thick layers of devitrified welded tuff, with some bedded vitric tuff and lava flows. Water temperatures in wells range from 25° to 72 °C; the warmest water is from wells about 450 ft deep completed in Idavada Volcanics near Banbury Hot Springs.

South of Hollister in the bottom unit, apparent resistivities increase with depth to greater than about 300 ohm-m below about 5,000 ft. Near Rogerson, apparent resistivities are less than 100 ohm-m to depths of more than 8,000 ft, and no contact between the Idavada Volcanics and the underlying rock is evident. In profile A-A', lack of a distinct electrical separation between the middle and bottom units may be due to a similarity in the electrical resistivities of the two units caused by thermal water migrating upward from depths greater than about 8,000 ft.

Because no wells completely penetrate the Idavada Volcanics, the nature of the underlying rock in the bottom unit cannot be determined. However, Rember and Bennett (1979) suggested that rocks underlying the Idavada Volcanics may be pre-Tertiary sedimentary rocks composed chiefly of Paleozoic marine sediments.

CONCEPTUAL MODEL OF THE SYSTEM

The conceptual model of the Twin Falls hydrothermal system is based on available geologic, hydrologic, and geophysical data. Although the model is a simplification of the actual physical system, it is consistent with known constraints and represents a first approximation of the configuration of the system. Additional data from several deep test holes in the area would add considerably to the detail with which the system could be described.

Model boundaries are arbitrary but are based on available data. Thermal water is pervasive throughout much of south-central Idaho and most of Twin Falls County. However, no thermal water is reported north of the Snake River on the Snake River Plain, so the Snake River canyon was assigned as the northern limit of the conceptual model. Water with temperatures of about 45 °C flows at land surface from wells 760 to 1,500 ft deep near Jackpot, Nev., and near Castleford on Salmon Falls Creek. Because this water is chemically or isotopically unique, it is presumed to be separate from the Twin Falls hydrothermal system, so the southern and western boundaries of the model were drawn on the basis of that presumption. Although the drainage divide of Salmon Falls Creek is considered the southern boundary of the study area, the southern boundary of the model area is along the base of the Rock Creek Hills. The western boundary is along Salmon Falls Creek. The eastern boundary extends northward from the Snake River canyon just east of Twin Falls to the base of the Rock Creek Hills and separates the distinctive thermal water in the Twin Falls system from lower temperature water farther east. Total surface area of the conceptual model within these boundaries is about 620 mi².

The conceptual model proposes a single thermal aquifer about 2,000 ft thick with a volume of 240 mi² in the Idavada Volcanics. About 12 mi south of the southern boundary, 45.5 °C water issuing from rhyolite at spring 16S-17E-31AC1S may indicate that aquifers in the Idavada Volcanics extend much farther south than currently available data imply. However, a silica concentration of 23 mg/L in the spring water implies that limestone or other Paleozoic rocks are the principal aquifer material. The high temperature of the spring may indicate a local convection system where water has circulated to a depth sufficient to attain those temperatures and has returned to the surface along faults.

Meteoric water from the low mountains south and southeast of the study area, possibly as far away as the Nevada border, recharges the hydrothermal system, probably after some near-surface evaporation. Depletion of the stable isotopes in the thermal water indicates that the water was recharged when the climate was much cooler. Recharge water percolates downward, probably to depths of about 3,000 ft, and migrates northward in aquifers in the Idavada Volcanics. The existence of a near-surface heat source is not evident; rather, the water is heated by conduction during deep circulation through the system. Some convective heat transfer is indicated by water temperatures of about 30 °C in wells less than 700 ft deep. The dilute nature of the thermal water (generally less than 350 mg/L total dissolved solids) probably is indicative of low reservoir temperatures and the nature of the host rock, rather than short residence time in the system or an old system where most of the more soluble minerals have been dissolved from the reservoir rock. Age of the thermal system probably predates the last glacial advance, but the volume of rock is sufficiently large that soluble minerals

continue to be dissolved at temperatures probably well below 90 °C but at least nearly 50 °C.

SUMMARY AND CONCLUSIONS

Interpretations of electrical resistivity soundings indicate that the Twin Falls hydrothermal reservoir potentially comprises about 240 mi³, or about 3.5 x 10¹³ft³; aquifers are contained principally in the Idavada Volcanics. Temperatures of water from wells completed in the upper part of the reservoir range from 26° to about 50 °C. Lewis and Young (1982) reported water temperatures of 72 °C from wells in the Banbury Hot Springs area, northwest of the study area; however, this water may be from a different system. On the basis of chemical geothermometers, estimated water temperatures in the hydrothermal system may be about 70° to 80 °C, although use of geothermometers for estimating reservoir temperatures in low-temperature systems such as Twin Falls may be unreliable and the results misleading.

Geophysical data and drillers' logs indicate that the hydrothermal system is continuous over the entire study area. Aquifer thickness ranges from about 700 to 3,000 ft; average thickness is probably about 2,000 ft. Although the continuity of the system appears to be disrupted along the northern and western boundaries, underflow from the system probably continues northward and mixes with other water of different origins. Lewis and Young (1982, p. 20) discussed results of such mixing on water sampled in the adjacent Banbury Hot Springs area.

Information concerning the physical characteristics of the reservoir, such as temperature, storage coefficient, transmissivity, pressure, and porosity is limited; consequently, construction of a conventional mathematical model to quantify the system is impractical at this time. Yeamans (1983), working in the Basin and Range province, and Young and Lewis (1982), working in southwest Idaho, used a lumped-parameter approach to quantify certain aspects of hydrothermal systems. By this approach, the input or output of a system can be measured or estimated, and detailed knowledge of intermediate processes becomes less important because of the combined effect on the input-output relation. In the Twin Falls area, the lumped-parameter approach can be used to estimate various quantities associated with the energy (heat and mass) output of the system.

Pearson and Truesdell (1978) calculated the T (tritium) content at any point in a well-mixed reservoir for some transit time (t) as

$$dT/dt = Q/V(T_o - T) - \lambda t \quad (2)$$

where

T = tritium content at any point,
 T_0 = tritium content in recharge water,
 Q = volume of recharge or discharge,
 V = reservoir pore volume,
 t = transit time, or age of sample, and
 λ = decay constant for T ($\ln 2$ /half life T).

The ratio of volume to input or output (V/Q) is identical to the average transit time (t) or average age of water leaving the system (Bolin and Rodhe, 1972, p. 327).

During 1985, water samples obtained from several wells in Twin Falls County that were thought to yield unmixed water were analyzed for carbon isotopes. On the basis of uncorrected values for ^{14}C , preliminary estimates of the age of the water ranged from about 1,000 to about 15,000 years; the water becomes progressively older downgradient along anticipated ground-water flowpaths (R.H. Mariner, U.S. Geological Survey, oral commun., 1986). After further examination of the SOLMNEQ analysis of the water and discussions with R.H. Mariner, many of the unmixed water samples were determined to be unsaturated with respect to dolomite and supersaturated with respect to calcite. Most of the ^{14}C analyses, therefore, would be unreliable or uninterpretable because of the difficulty of determining how much of the carbon originated as dolomite and how much was lost through precipitation of calcite. Subsequent work by Mariner further indicated high concentrations of dissolved helium and presumably "dead" carbon in some of the water probably are due to the Twin Falls thermal water mixing with some older water from aquifers beneath the Snake River Plain.

However, several of the samples were not supersaturated with respect to calcite and contained near-background levels of dissolved helium. Carbon-14 ages of these samples ranged from about 1,000 to 10,000 years; the younger water was from the upper end of the system near Hollister, and the older water was from the lower end of the system near Buhl. These two ages seem reasonable, at least for comparison purposes, for the Twin Falls system.

If the age of 10,000 years is representative of flow duration or transit time through the entire system, and if the estimated reservoir volume is 240 mi^3 , applying the relation $t = V/Q$, recharge to the system ranges from about 5.5 ft^3/s for a reservoir with a pore volume of 0.05 percent to about 11 ft^3/s for a reservoir with a pore volume of 0.10 percent. Sensitivity of the recharge estimate to variation in each of the properties for a 240- mi^3 reservoir is shown below:

Age of water (years)	Reservoir pore volume (percent)	Recharge	
		(ft ³ /s)	(acre-ft/yr)
5,000	0.05	11	8,000
	.10	22	16,000
10,000	.05	5.5	4,300
	.10	11	8,000
15,000	.05	3.7	2,700
	.10	7.4	5,400

Porosities in rhyolitic rock can vary widely. Brott and others (1978) obtained porosities of 0.05 from laboratory analyses of core samples of silicic volcanic rock. Rhyolitic core samples analyzed by Sorey and others (1978, p. 19) for their numerical simulation model ranged from 0.47 for tuffaceous material to 0.06 and 0.07 for silicified and flow rocks; values of 0.10 and 0.05 were used in the model. For a reservoir volume greater than 240 mi³, estimates of recharge to the system would increase.

In the conceptual model for the hydrothermal system, heat is discharged primarily as ground-water underflow toward the northwest. Some heat is discharged conductively at the surface. Natural heat discharge from springs is not apparent; heat once was discharged in water from the Banbury Hot Springs and presently is discharged in water from Nat-Soo-Pah Warm Spring. However, water from each of those springs is of a different chemical and isotopic character, and neither of the springs nor their discharged heat is considered to be part of the Twin Falls system.

The amount of heat energy (H) being removed advectively from the system in ground-water underflow can be determined from the relation:

$$H = Qc \quad (3)$$

where Q is ground-water discharge from the system and c is heat content of the water in calories per gram. If the system is assumed to be in equilibrium, discharge and recharge values would be the same. Although some heat presently is being removed from the system in thermal water used for space heating, greenhouse operations, and aquaculture, the amounts are not considered here in the estimate for natural heat flux out of the system. If the temperature of the water at the outflow boundary is assumed to be about 46 °C, which is the warmest measured during this study, and not the higher temperatures estimated using the chemical geothermometers, then the amount of heat energy being removed

advectively from the system can be determined from equation (3). Actual amount of heat being removed advectively and expressed as heat flow over the entire surface area of the system as a function of discharge is shown in the following table:

Age of water (years)	Reservoir pore volume (percent)	Discharge (ft ³ /s)	Convective heat discharge at 46 °C	
			(cal/s x 10 ⁷)	HFU's over 620 mi ²
5,000	0.05	11	1.4	0.9
	.10	22	2.8	1.8
10,000	.05	5.5	.8	.5
	.10	11	1.4	.9
15,000	.05	3.7	.5	.3
	.10	7.4	1.0	.6

Heat being discharged from the system in the water ranges from 0.5 to 2.8 x 10⁷ cal/s (0.3 to 1.8 HFU's) and is a function of the volume of water discharged, which, in turn, is based on average transit time of water through the system. If the measured temperature is minimal and reservoir temperatures estimated from chemical geothermometers are between 70° and 80 °C, then the amount of heat being discharged advectively from the system would be proportionally greater. However, because of the unreliability of using chemical geothermometers to obtain reservoir temperatures in low-temperature systems, use of other than measured temperatures may not be justified.

Heat discharged conductively from the system at the surface is difficult to quantify because of a lack of thermal gradient data and thermal conductivity measurements of rock samples. A temperature log from well 13S-15E-1DAD1 indicates an average conductive gradient of 0.017 °C/ft at depths between 1,100 and 1,660 ft. Bottom-hole temperatures in other wells in the area are 31° and 32 °C at depths of 1,200 and 1,600 ft; these temperatures and depths equate to gradients of about 0.018 and 0.014 °C/ft. When projected downward, these gradients indicate temperatures of 50°, 80°, and 100 °C at depths of 3,100, 5,000, and 6,300 ft. Reservoir temperatures of 100 °C are not indicated by any of the available chemical geothermometers, and other temperatures as high as 80 °C may not be valid. Electrical resistivity data indicate the top of the principal thermal aquifer is considerably less than 5,000 ft below land surface and is commonly about 1,000 ft; depths to the center of the aquifer range from about 1,200 to 3,000 ft. The presence of 50 °C water at the 3,000-ft depth indicated by the

temperature gradients is within the limits of the thermal aquifer indicated by the geophysical data and could be representative of maximum reservoir temperatures for the Twin Falls system.

If the average thermal gradient is 0.016 °C/ft and, based on an average thermal conductivity of $3.5 \times 10^{-3} \text{ cal}/(\text{cm} \cdot \text{s} \cdot ^\circ\text{C})$, for predominantly basalt with some rhyolite, then the conductive heat flow for the area would be $1.9 \times 10^{-6} \text{ cal}/\text{cm} \cdot \text{s}$, or about 2 HFU. From the preceding information, the resultant net heat flow (conductive + advective) for the area would be between 2.2 and 3.7 HFU's, depending on variables assigned.

The 3.7 HFU is an anomalously high heat flow for south-central Idaho and would be more representative for heat flow in an active geothermal area. The 2.2 HFU is more compatible with values for margins of the Snake River Plain published by Sass and others (1971) and Brott and others (1976, 1978) and probably is a better estimate for the Twin Falls area. The more credible lower value requires a system older than 5,000 years and recharge rates considerably less than 11 ft³/s. For a system of this size, transit times between 10,000 and 15,000 years and annual recharge between about 5 and 7 ft³/s are required to achieve an acceptable level of heat flow. If temperatures hotter than 50 °C are assumed for the system, then even longer transit times or lower recharge rates are required.

In this report, all values presented are best estimates and are based on a coarse configuration of the conceptual model indicated by electrical resistivity soundings and other available data. As new data become available, the conceptual model for the system undoubtedly will change, and more accurate and reliable estimates of recharge and heat flow can be made.

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